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of the
AIR POLLUTION CONTROL ASSOCIATION

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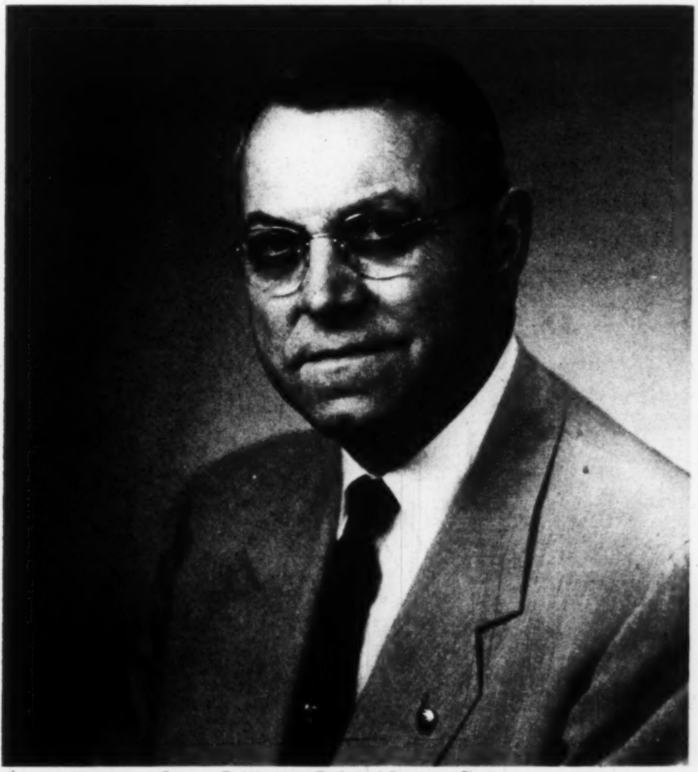
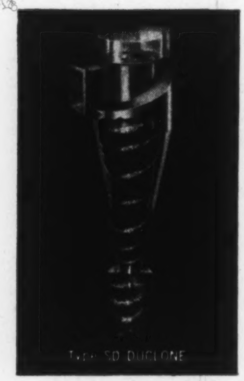


George T. Minasian, Technical Program Chairman, 54th Annual Meeting, New York, New York.



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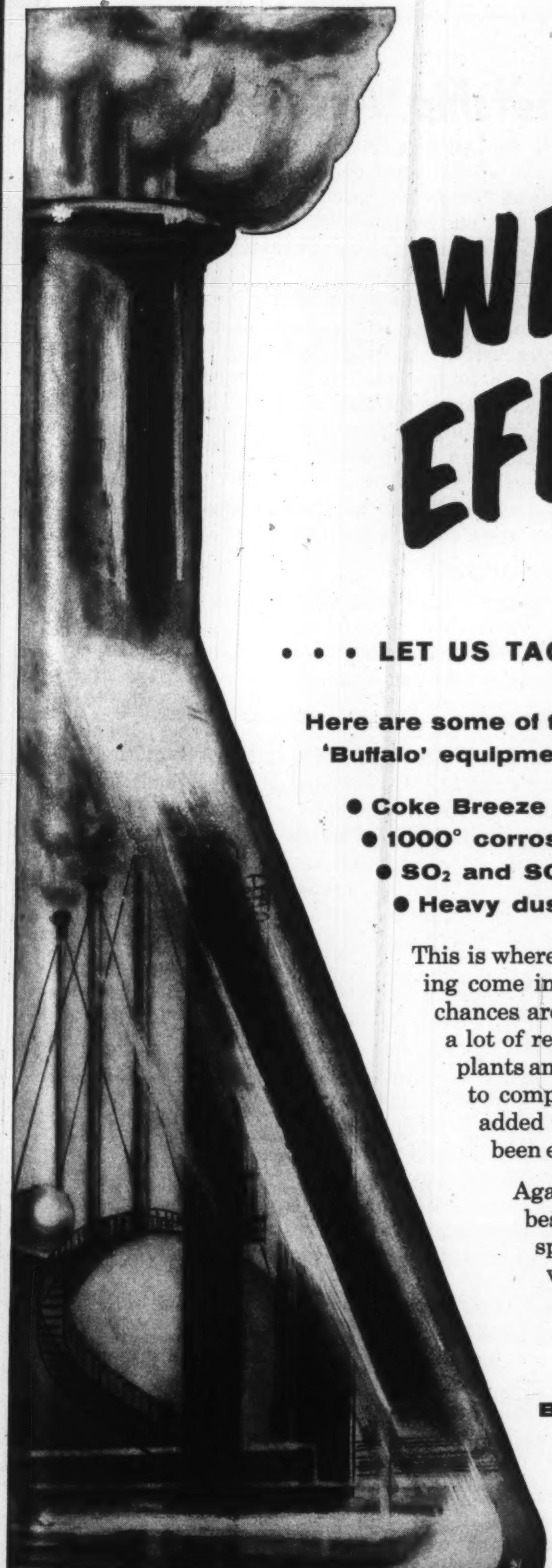

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LETTERS to the EDITOR

Dear Editor:

I, as a new member of the Air Pollution Control Association, have been particularly edified with the *APCA Abstracts* since, for a newcomer, they offer an excellent survey of what is of interest in this field.

However, I do have one suggestion. If the Abstracts were to include the address of the senior author, those interested could then write for reprints of articles of interest without having to have recourse to visiting a library to obtain the address of the author. In addition, many of the journals reviewed are not easily available.

Sincerely
F. C. Dohan, M.D.
Medical Director
Radio Corporation of America

Dear Dr. Dohan:

We wish to thank you for your kind remarks about *APCA Abstracts*.

APCA Abstracts include three index numbers a year, the Subject Index issue published in July, the Author Index issue in August, and the Journal Index issue in September.

Standard bibliographies do not usually list addresses of senior authors, presumably since many authors are not in a position to supply reprints of their articles.

The purpose of the Abstracts, of course, is to supply its readers with a permanent reference of all articles of interest. In November 1958 by negotiating an agreement with the U. S. Public Health Service, the number of Journals covered was increased to about 350, many in the foreign language field.

We are very pleased to honor requests from members for assistance in obtaining reprints.

Editor

PR HANDBOOK AVAILABLE

Joseph H. McGinty, APCA's Public Relations Chairman, announced that the committee's Public Relations Handbook is now completed. It may be obtained by writing Headquarters.

SECRETARY'S PAGE

"Membership Accelerates"

Of great interest to the entire membership is the progress of the intensive membership campaign being conducted by Dr. W. L. Faith, First Vice President and Membership Committee Chairman. About 2000 invitations were sent out by him with the last copy of the Air Pollution Foundation's Newsletter. Approximately 750 invitations were mailed from Pittsburgh in response to the names furnished by the membership to Dr. Faith in his letter asking for prospects. Results have been most encouraging. In the month of January alone 81 new members were added to the rolls, including seven corporate memberships. It is safe to predict that by the end of February APCA's membership will be over the 2000 mark. This is a fairly conservative estimate. This further proves that a well co-ordinated active membership campaign can produce results. The number of prospects contacted can be counted upon to return a certain number of new members. Larry Faith is to be congratulated for his efforts in behalf of the association's membership drive.

Technical Council Re-Aligned

The formal machinery for approving formation of new committees as recommended by the board to the technical council, approved by the technical council and in turn approved by the board of directors by letter-ballot has been consummated. On another page of this *Journal* the new organization chart of the association is displayed. The new committees which are now functional include as part of the technical council, the TR-3 Economic Effects, TR-4 Radiation, and the TA-10 Vehicular Exhaust. Deactivated and abandoned are the TA-1 Heating Equipment, TI-10 Locomotives, Steam & Diesel Committees. Combined with the TI-7 Ferrous Foundries is the TI-9 Non-Ferrous Committee. Redesignated are the TA-6 Stokers Committee to Coal Utilization and TA-9 Power Boiler Equipment to Power Boiler Equipment Information Committee. Established as service committees are S-8 Planning and Zoning Committee, S-9 Consultants Committee, S-10 International Affairs Committee and S-11 Education and Training Committee. Chairmen named for new committees. Named by President Harry A. Belyea as Chairmen of these new committees are as follows:

TA-10 Vehicular Exhaust—Smith S. Griswold, Air Pollution Control Officer, Los Angeles County
TR-3 Economic Effects—George Wasser, Industrial Hygienist, Air Sanitation Program, State of New Jersey
TR-4 Radiation—Not filled at press-time.
S-8 Planning and Zoning—Benjamin Linsky, Air Pollution Control Office, San Francisco Bay Area
S-9 Consultants—Ernest R. Roth, Senior Consultant of Roy F. Weston, Inc.
S-10 International Affairs—Dr. Robert E. Swain, Professor Emeritus, Stanford University
S-11 Education and Training—Professor E. R. Hendrickson, University of Florida

These Chairmen have been charged by the Board of Directors to make their own terms of reference for these committees, and have been authorized to staff their committees from among the membership of the association.

Great Loss Suffered

It is with deep regret that we announced at press-time for the February *Journal* the death of Ellis Smauder, President of the American Incinerator Corp. in Detroit and a former Board Member of APCA. For the past year, in spite of an extemely heavy work schedule, Ellis Smauder had been revitalizing the Incinerator Committee.

JOURNAL OF THE
AIR POLLUTION CONTROL
ASSOCIATION

**A Monthly Journal
Devoted to
Air Purification**

**Editor: Arnold Arch
Associate Editor: Pat Truschel
Assistant Editor: Pat Martin**

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**AIR POLLUTION CONTROL
ASSOCIATION
4400 Fifth Avenue
Pittsburgh 13, Pa.**

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The Editor welcomes writers interested in air pollution problems and encourages them to use the pages of this journal for the expression of their opinions. But neither he nor the Association assumes responsibility for the validity of the opinions expressed herein.

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THE 1961 APCA EXPOSITION

54TH ANNUAL MEETING

Hotel Commodore, New York, New York

June 11 to 15

- ***Each year the APCA holds its annual meeting and exposition in various centers of industry, this year New York City has been chosen as the meeting headquarters. It is important to recognize that in scope the objectives are to:***
  - ***Furnish a common ground for the exchange of technical information.***
  - ***Stimulate development progress.***
  - ***Document the year-to-year progress in the constantly expanding field of Air Pollution Control.***
- ***A high calibre of Air Pollution Control specialists from industry and government are expected to attend. This is because of the unprecedented interest in new control techniques devised to meet the requirements of Air Pollution Control.***
- ***Exposition represents an unduplicated opportunity to communicate newly developed capabilities and PRODUCTS to an audience which will not be congregated again under one roof in 1961.***

ALL ADS FOR THE MAY CONVENTION ISSUE OF THE *JOURNAL*

DUE BY MARCH 31.

Research on CONTROL OF EMISSIONS from Bessemer Converters*

ALEXANDER R. ORBAN, JOHN D. HUMMELL, Principal Mechanical Engineers,
and **GEORGE G. COCKS,** Project Leader in Microscopy, Battelle Memorial Institute,
Columbus, Ohio

In 1856, the English inventor, Henry Bessemer, announced the details of his method for decarbonization of pig iron by forcing a blast of air upward through a bath of molten metal. In 1860, the first commercial Bessemer steel was produced at Sheffield. Because of its simplicity and speed, the use of the process spread rapidly. The spectacular flame and dense, reddish-brown smoke characteristic of the method became a familiar sight in steelmaking centers. The growth of the use of the method was checked somewhat by the introduction about 1868 of the open-hearth process, which is slower but gives a wider range of product composition, and more recently by the Linz-Donawitz oxygen converter; but large Bessemers continue to be competitive for producing many types of steel.

Although the process incidentally oxidizes some iron, it principally oxidizes the carbon, silicon, and manganese in pig iron. In so doing, it releases large quantities of heat which makes the process self-sustaining without additional fuel and results in conversion of the molten bath of pig iron into a type of steel which is desirable for many uses such as tubing, wire, bars, and concrete-reinforcing rods.

Varicolored smoke emanating from steel mills has long been accepted as a part of the steelmaking process. In the past two decades, however, the steel industry has recognized that, as steel production capacity continues to increase, every effort should be made to minimize the resultant increase in air pollution. In this regard, the American Iron and Steel Institute and the various steel companies are conducting research and development programs and are installing extensive equipment for abatement of pollution.

In 1957, on invitation of the American Iron and Steel Institute, Battelle proposed a research investigation to establish means for control of smoke from pneumatic steelmaking processes. This paper is a progress report on the investigation.

Practical Operating Problems

The Bessemer converter is perhaps the most spectacular steelmaking process in the industry. In addition to the long brilliant flame and brown smoke, small to large particles of molten slag are emitted from the mouth of the vessel. Rapid accumulation of this slag in any hood or duct leading to a scrubber or other cleaner would cause severe operating problems. Furthermore, the Bessemer converter is controlled by an experienced operator who has learned through years of experience to judge the status of the melt inside the vessel by the visible condition of the flame above the unit. Because of this, the flame cannot be enclosed but must be in view at all times.

Normally, air is blown through the tuyères in the bottom of a converter at the rate of 30,000 to 35,000 cfm. In its traverse through the molten metal, the oxygen is consumed and carbon monoxide is formed. The metal and gases are heated to about 3000°F in the process. As the gas leaves the mouth of the converter the carbon monoxide burns to carbon dioxide. In addition, brown smoke is emitted. This smoke is mostly iron oxide which is formed when the submicron iron particles burn in the flame above the vessel. If the gases were to be collected in a hood or stack placed some distance from the mouth of the vessel, ambient air would be drawn into the duct. Assuming a five to one dilution of the exhaust gas, the temperature would be reduced to approximately 500 to 600°F and the gas volume at this temperature would increase to about 350,000 cfm.

To complicate the situation still further the converter operation is intermittent. Actual refining time is 12 to 15 min and charging and pouring time is about five to eight min. The possibility of one collecting device serving two converters was considered, but because of the comparatively short time for pouring a pair of collectors would have to operate simultaneously much of the time.

To collect, cool, and clean this huge amount of intermittent, smoke-laden exhaust gas presents a tremendous problem to the steel industry; hence, other means of abatement are being sought.

Literature Summary

As a part of the research program on Bessemer smoke abatement, a brief review of former work was made to determine the present status of cleaning converter gases.

No published work was found on work done in the United States on collecting smoke or on preventing its formation in the bottom-blown, acid-Bessemer converter.

In Europe, however, a number of investigations have been made on the basic-Bessemer converter.

H. Kosmider, H. Neuhaus, and H. Kratzenstein[1] conducted tests on a 20 ton converter to obtain characteristic data for dust removal and the utilization of waste heat. The sensible heat escaping from the converter represents a considerable loss. Measurements of dust concentration in the stack were from 0.132 gr/ft^3 to 0.393 gr/ft^3. Dust particle sizes collected were of the order of 0.5 to 2.0 microns. With steam addition to the blowing gas, practically no brown smoke was formed.

---

* Presented at the 53rd Annual Meeting of APCA, May 22–26, 1960, Netherland-Hilton Hotel, Cincinnati, Ohio.

The authors felt that the fine smoke was caused by the vaporization of iron in the bath. They also believed that preventing its development above the bath or outside the converter by simple methods, such as water sprays or water vapor, would be unsuccessful. Because of the submicron size of the dust, special equipment would be necessary to clean the exhaust gases.

W. Dehne[2] conducted a large number of experiments at Duisburg-Huckingen in a 36-ton Thomas converter using oxygen-enriched air in an effort to determine means for removing dust and smoke from the exhaust gases. This converter discharged into a stack. Particle-size measurements of the smoke showed them to be between 0.03 and 0.15 micron. A number of wet scrubbing and dry collectors were tried unsuccessfully. Best results for smoke removal were obtained by mixing steam with the oxygen-enriched air and by using electrostatic collectors. With steam addition, production fell off because of lower scrap consumption. A waste-heat boiler and electrostatic collector with necessary gas precleaners were felt to be the best solution for this particular plant.

Meldau and Laufhütte[3] determined dust particle size and size distribution in the waste gas of a bottom blown converter during the four-min dephosphorization blow. In an oxygen-enriched blast, their results show the particle size at the edge of the flame to be between 0.06 and 0.18 micron with a mean of 0.12 micron. In an air blast, sizes ranged from 0.03 to 1 micron with the mean being between 0.12 and 0.15 micron.

G. S. Sel'kin and N. I. Zadalya[4] describe the use of oxygen-water mixtures injected into a molten bath in refining open-hearth steel. They claim that the use of oxygen-water mixtures should increase the life of the furnace because of lower temperatures and less smoke. They state that when the gravimetric ratio of water to oxygen was between 0.5 to 0.9, the reaction temperature zone decreased from 3900 to 3270°F and the amount of dust formed was reduced to 33.3 to 20% of its previous level, and emission of brown smoke almost ceased.

W. Pepperhoff and C. Passov[5] attempted to find some correlation between the optical absorption data of the smoke and flame emission and the composition of the metal in a Thomas converter to determine automatically the metallurgical state in the melt. A detailed analysis was made of the light absorption and light scattering of iron oxide smoke, and the emission of converter smoke was carefully investigated. Their conclusion was that although the total amount of smoke can be determined during the reaction time, one cannot use the measured emission and absorption data for determining the metallurgical reactions because the situation involving the flame and smoke is too complex.

P. K. Gledhill, P. J. Carnall, and K. H. Sargent[6] report on cleaning the gases from oxygen lancing of pig iron in the ladle. They claim the Pease-Anthony Venturi scrubber removed 99.5+ % of the smoke, thereby reducing the concentration to 0.1 to 0.2 g/ft^3, which resulted in a colorless stack gas after the evaporation of water. A description of the cleaning equipment is also given.

From review of all of the published information on the subject, it is concluded that a suitable solution to the smoke elimination problem has not been found.

Accordingly, it was deemed desirable to investigate the feasibility of preventing the formation of smoke.

Mechanisms of Smoke Formation

Two conflicting theories on the cause of iron oxide smoke formation have been advanced. The first and most generally accepted explanation is the iron vaporization theory. The other is the iron carbonyl theory.

In the vaporization theory, it is believed that the exothermic reaction of oxygen and iron causes an instantaneous high temperature at the reaction zone causing the iron to vaporize. The vapor pressure of iron increases considerably with increase in temperature. These vapors condense in their travel through the molten metal with nitrogen and carbon monoxide gas. When the condensed vapors come in contact with the air outside the converter, they oxidize and form brown smoke. Kosmider, Neuhaus, and Kratzenstein[1] calculated the reaction temperatures during dephosphorization to be about 4170°F for an air blow, about 4800°F for 35% oxygen-enriched air, about 5500°F for pure oxygen, and about 3500°F for a 1:1.2 oxygen steam ratio. Naeser, Pepperhoff, and Riedel[9] measured metal temperatures as high as 4170°F through the bottom tuyère in a converter using oxygen-enriched air.

In the early stage of an acid Bessemer blow, when the highly exothermic oxidation of silicon and manganese takes place, smoke emission is small. During the carbon blow, however, when the mildly exothermic oxidation of iron to FeO and the reaction of FeO to Fe + CO takes place, smoke emission becomes more pronounced and it increases in intensity as the carbon decreases.

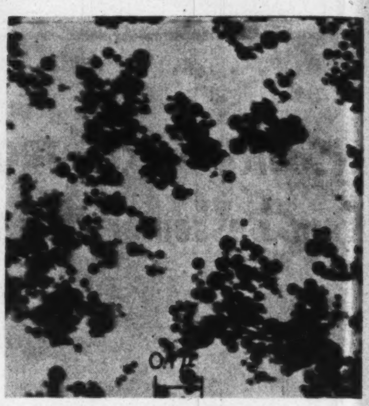

Fig. 1. Electron photomicrograph of smoke sampled during an air blow.

In other steelmaking processes such as the top-blown oxygen converter, oxygen-lancing of the open hearth, and the top-blown Tropenas converter, brown iron oxide smoke is strongly evident.

The addition of sufficient steam with the blowing gas practically eliminates the formation of brown smoke. It is generally believed that the cooling effect produced by the endothermic reaction on dissociation of steam to hydrogen and oxygen at high temperatures may prevent the high reaction temperatures and resultant iron vaporization from occurring. Carbon dioxide has an even higher cooling capacity on dissociation than does steam. However, available literature[7, 8] and private correspondence regarding the use of carbon dioxide indicate that it does not eliminate smoke. Consequently, steam must do something more than simply cool the reaction zone.

The iron carbonyl theory is based principally on work by Kohlmeyer and Spandau[10] and Jazwinski.[11] Their experiments indicate that ferrous oxide was formed when the oxidizing gas met the surface of the bath and that this reacted with iron carbide to form iron carbonyl. This then dissociates to iron and carbon monoxide, the iron then being oxidized to form the brown smoke. However, because iron carbonyl is unstable at high temperatures, there is some doubt that this can cause smoke. Casting further doubt is the fact that iron carbonyl cannot account for the heavy smoke prevalent during the afterblow of a basic converter when there is little carbon present.

Sampling of Emissions

To analyze completely the smoke problem of an acid converter, information on the exhaust gas conditions and smoke characteristics was needed. Although some published information was available on basic Bessemer converters discharging into stacks, none was available on acid converters discharging into the atmosphere as is the custom in this country. Through the co-operation of the National Tube Division, U. S. Steel Corporation, Mc-

Keesport, Pa., a 30-ton acid Bessemer converter was made available for smoke sampling.

Thermocouples were supported in the plume on a 115-ft crane boom at various elevations above the mouth of the converter, depending on the length of the flame. At about five to 10 ft above the tip of the flame, the bare thermocouple temperatures were between 600 and 700°F. At about 10 to 15 ft above the tip of the flame, the bare thermocouple recorded between 400 and 500°F. The maximum temperature recorded was 1750°F when the end of the boom was directly in the tip of the flame for a short period during a steam blow. An aspirating thermocouple read approximately 1300°F at this point.

The unexpectedly low gas temperatures were probably caused by excess air drawn into the hot gas and by radiation to the general surroundings.

To collect dust samples, a standard portable MSA electrostatic precipitator was modified to operate remotely from the end of the 115-ft mobile railroad-crane boom. In addition to the standard precipitator tubes, a slotted tube was fabricated to receive a glass slide for particle-size determination. The polyethylene insulating bushings inside the precipitator hand gun were replaced with Teflon which is more resistant to the higher temperature. To the inlet end of the aluminum precipitator tube, a four-in. removable tube containing a Chromel-Alumel thermocouple was secured for gas temperature measurements. A $^5/_8$-in. copper tube inside the pipe boom connected the electrostatic precipitator on the end of the boom with the vacuum pump on the ground. The high-voltage leads and the thermocouple wires were similarly connected.

The gas-flow rate of two ft^3/min through the precipitator was measured by a calibrated rotometer. At this flow rate virtually all of the smoke was deposited on the walls of the sampling tube. Gas temperature was recorded on a recording potentiometer. The instrument was held in the smoke approximately 15 to 20 ft above the converter mouth for periods of one to three min.

Table I shows the dust concentration and composition of samples taken in the exhaust gas of a typical bottom-blown acid-Bessemer converter.

Smoke loading during an air blow averaged about 0.2 lb of dust per 1000 lb of gas sampled, and during a steam-air blow, it averaged approximately 0.08 lb of dust per 1000 lb of gas sampled. Approximately the same dust loadings during air blowing had been reported by Kosmider, Neuhaus, and Kratzenstein.[1]

The smoke composition as determined by an emission spectrograph was primarily iron oxide with small amounts of other constituents. The unexpectedly high amounts of silicon and manganese in the smoke during the end-of-blow samples probably came from the vessel lining and the slag, respectively, as a result of the higher temperature and slag fluidity during this time.

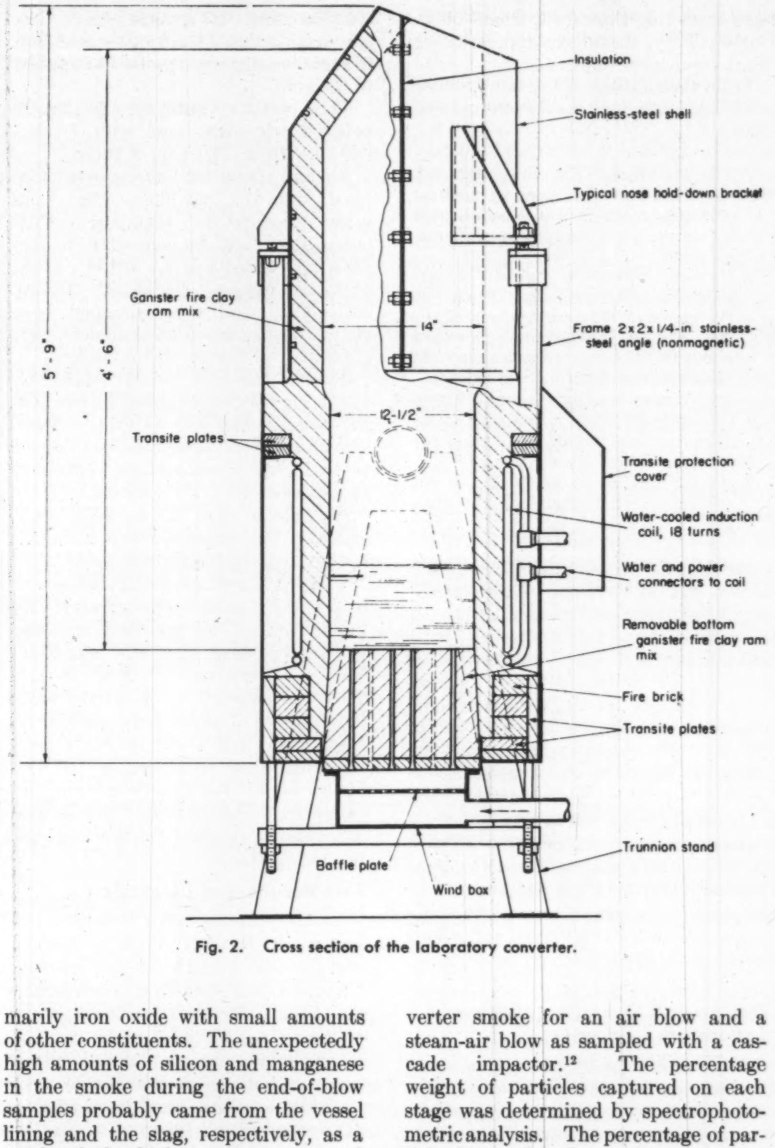
Insulation
Stainless-steel shell
Typical nose hold-down bracket
Ganister fire clay ram mix
14"
Frame 2x2x1/4-in. stainless-steel angle (nonmagnetic)
5'-9"
4'-6"
12-1/2"
Transite plates
Transite protection cover
Water-cooled induction coil, 18 turns
Water and power connectors to coil
Removable bottom ganister fire clay ram mix
Fire brick
Transite plates
Trunnion stand
Baffle plate
Wind box

Fig. 2. Cross section of the laboratory converter.

At all stages of the blow electron photomicrographs of dust samples taken with glass slides mounted on the electrostatic-precipitator tubes showed individual particles as small as 0.01 micron. Many of the particles had agglomerated or chained into larger units.

Figure 1 is an electron photomicrograph of smoke particles taken during an air blast. As can be seen, a transparent film appears to coat each particle. X-ray diffraction analysis indicates primarily Fe_3O_4 plus small amounts of alpha Fe_2O_3, which may be in the core. Close examination shows the particles to be spherical and cubic in shape.

Table II shows the approximate particle-size distribution in the converter smoke for an air blow and a steam-air blow as sampled with a cascade impactor.[12] The percentage weight of particles captured on each stage was determined by spectrophotometric analysis. The percentage of particles larger than five microns captured on the first stage was omitted because the weight captured on the classifying stages was of the order of 25 to 100 μ gm, and one or two large particles on the first stage would erroneously affect the weight percentage of the succeeding stages.

Because of the characteristics of a cascade impactor, most of the particles smaller than 0.15 micron pass beyond the last stage. However, a reasonable estimate of this might be one to five % by weight.

The significant factor to be noted on this table is that about 50% or more of the particles in an air blow are below 0.3 micron in size as against only about 13% for a steam-air blow. Because of the higher dust loading and the smaller particle size, the smoke from an air blow results in more pronounced light scattering than for a steam blow. Consequently, the smoke appears more dense from an air blow.

From the analysis of the samples and results, the following conclusions may be drawn:

1. Many of the particles are less than 0.1 micron in size with some as small as 0.01 micron, which cannot be collected by conventional equipment of practical size.
2. By x-ray diffraction analysis the particle composition is largely Fe_3O_4.
3. By emission spectrographic analysis the smoke composition averaged about 90% Fe_3O_4 with small amounts of other constituents.
4. Particulate loading is about 0.2 lb of dust per 1000 lb of gas with an air blow and about 0.08 lb of dust per 1000 lb of gas with steam-air blow.
5. An air blow has a much higher percentage of very small particles than does a steam-air blow.

Agglomeration of particles by sonic forces was given some consideration. No known successful installations of large-scale sonic agglomerations have been made and little information is available on which to base a design. In general, gas velocities through sonic agglomerating chambers are from four to 10 fps. Dust concentration in the chambers should be of the order of one gr/ft³. Adjustment of the frequency of the sonic generator to give maximum collision between particles is difficult. A sonic precipitator to clean the large gas volume from a converter would be huge and a considerable amount of experimental work would need to be done before its feasibility would be clear.

Design and Operation of the Laboratory Converter

In an effort not only to find practical and economical means for the elimination of smoke from a Bessemer converter but also to determine the mechanism of smoke formation, a small converter, which closely simulates the operation of a full-scale vessel, has been constructed at Battelle.

Figure 2 shows a cross section of the laboratory converter. The unit had an inside diameter of 12½ in. and an inside height of 54 in. It was mounted on a trunnion to simulate turnup and turndown conditions.

Auxiliary heat was supplied to the metal in the converter to compensate for the relatively high cooling effect resulting from its small size. This heat was furnished by means of a high-frequency induction coil. Power to the coil was supplied by a 100-kva motor-generator set. Power losses in the cable were approximately 25 kw. Normally, a maximum induction power was used on all test heats.

The supporting frame was made of stainless steel. At several places, electrical continuity of the frame was broken to avoid heating when power was applied to the coils.

The bottom contained 20 tuyère holes which were lined with 3/16-in.-OD (0.1275-in.-ID) copper tubing.

Air and steam for blowing were supplied from the building systems and were measured by standard ASME sharp-edged orifices connected to differential manometers. Other gases, such as oxygen, hydrogen, helium, NH_3, CH_4, and CO_2, obtained from standard compressed-gas cylinders, were measured by calibrated rotameters.

Twelve hundred pounds of Chateaugúe pig iron were melted in two 600-lb melting furnaces. Carbon, ferrosilicon, and ferromanganese were added to make up a composition containing approximately 4.0% carbon, 1.5 to 1.7% silicon, and 0.5 to 0.7% manganese. The converter was preheated by burning coke inside the unit.

Usually, seven consecutive heats were made, each using approximately 300 lb of metal. The first heat was considered a preheat blow and was blown with air enriched to 25% oxygen. This was followed by six experimental blows, three of which were made using fresh metal and three alternate heats were made by recarburizing the previous heat. Recarburizing was accomplished by adding the proper amounts of graphite, ferrosilicon, and ferromanganese.

Test Results and Discussion

In the operation of a Bessemer converter, the blowing of air or oxygen-enriched air through the molten-metal bath produces steel from blast-furnace pig iron. During this transition, a continual change takes place, not only in the metal but also in the effluent gases and dust. A number of these variables were measured in an effort to determine their effect on smoke reduction when changes in blast-gas composition and additions of gases and solids were made in the nose of the vessel.

Exhaust-Gas Dust Loading

Smoke samples from the laboratory converter were collected in the stack above the vessel. These were taken to determine the change in quantity of smoke emitted when changes in blowing technique were made.

Exhaust gases from the laboratory converter discharged directly into a hood and existing stack over the vessel. A short distance above the hood, the gases were directed into a 12-in.² horizontal duct which guided them into a 3000-cfm exhaust fan. Figure 3 is a photograph of the exhaust duct and sampling equipment. Gas velocity in the duct was controlled by a damper and was measured by a calibrated orifice and manometer. A mixing baffle and straightening vanes were located upstream of the orifice.

Smoke samples were collected on a Fiberglas filter mounted in a holder which was inserted in the gas stream. Isokinetic conditions were maintained at the filter entrance. Gas drawn through the sampling equipment was measured by a calibrated rotameter and a gas meter.

Dust loading in the effluent gas of the laboratory was not consistent between one blow and another, even though blowing conditions apparently were similar. This was probably caused by the continuous changes which take place during the blowing cycle.

Table III shows the average dust loading in the converter exhaust gas when blowing with air.

These values are based on the exhaust gas as it leaves the converter mouth, a correction having been made for dilution.

Table IV shows the average dust loading in the converter exhaust gas

Table I—Dust Concentration and Composition in the E of

Samples Taken Appro

		Dust Concentration									
		Lb Dust per 1000 Lb Exhaust Gas Sampled		Grains per Ft³							
Time and Type of Blow	Sample	Per Sample	Avg	Per Sample	Avg	Fe_3O_4 a	SiO_2	MnO_2	Al_2O_3	Ca	Sm Ni
Beginning of blow, 0 to 4 min after turnup	39	0.162	—	0.085	—						
	4	0.359	0.178	0.189	0.093	95	2.0	0.5	2.0	0.	0.0
	5	0.01338	—	0.007	—						
Middle of blow, 4 to 8 min after turnup	32	0.523	—	0.275	—	97	2.0	0.8	0.07	0.	0.0
	46	0.220	0.371	0.1155	0.195						
End of blow, 8 to 11 min after turnup	215	0.1895	—	0.0995	—	89	6.0	4.0	0.3	0.	0.0
	53	0.182	0.218	0.0955	0.114						
	23	0.231	—	0.1215	—						
	214	0.268	—	0.141	—	90	5.0	4.0	0.1	0.	0.0
Turnup	205	2.150	2.150	1.13	1.13	98	1.0	0.2	0.3	0.	0.0
Turndown	60	0.380	0.332	0.200	0.175	96	2.0	0.5	1.0	0.	0.0
	200	0.285	—	0.1495	—						
Steam-air, 3 to 7 min after turnup	11	0.1113	—	0.0568	—						
	210	0.0576	0.077	0.0303	0.040	93	4.0	0.5	1.0	0.	0.0
	206	0.063	—	0.033	—						
O_2-air, 2 to 5 min after turnup	201	0.636	0.458	0.335	0.241	93	4.0	0.8	1.0	0	0.0
	218	0.281	—	0.148	—	98	1.0	0.5	0.1	0	0.0

Notes: Percentages arbitrarily reported as oxides. N. D., not detected; t, trace; *a* F_3O_4 calcu der during various parts of the blow when blowing with air enriched to 22 to 24% oxygen.

The dust loadings when blowing with air in the laboratory converter are comparable to those collected above the nose of a commercial vessel in December 1957.

Smoke Composition

To compare the discharge products of the small laboratory converter with those of a commercial vessel, a number of smoke samples were analyzed by chemical methods and by the emission spectrograph.

Table V shows the approximate composition of smoke from a commercial vessel as compared with that from the laboratory unit. In both cases, the minor constituents, which composed less than 1% of the total, were omitted from the table. The analytical method used analyzes the elemental constituents present which were then calculated as oxides as shown in the table.

The reason for the low content of iron and high content of silicon and manganese in the smoke of the laboratory vessel has not been established. However, for the silica, this might result from the high ratio of the area of silica lining to the weight of metal in the bath as compared with this ratio in a large converter. This ratio was approximately five times higher in the laboratory vessel than that of a commercial unit.

In samples from both the commercial vessel and the laboratory vessel a trend indicates that, as the blow progresses, the iron oxides decrease and silicon and manganese oxides increase. The only apparent reason for this is the increased ejection of minute particles of slag due to the increased fluidity of the slag as the temperature increases toward the end of the blow.

The data available are too few to permit definite conclusions as to the effect of different compositions of the blast on the composition of the smoke.

Particle Size of Smoke

To determine the difference in particle size of the smoke when blast-gas conditions were changed, samples were collected from the exhaust-gas stream for examination under the electron microscope. An electrostatic precipitator with a microscope slide mounted on the collection tube was used for obtaining the sample.

Figure 4 shows an electron photomicrograph of particles collected while blowing with air enriched to 23% oxygen. Figure 5 shows an electron photomicrograph of particles collected when 20 cfm of hydrogen was added to the blast gas which was enriched to 23% oxygen. Figure 6 shows an electron photomicrograph of particles collected while blowing air and 20 cfm hydrogen, but with the blast gas enriched to 24% oxygen. The difference in the number of particles on each photograph should not be construed as a measure of smoke density, because the sampling time for each sample was different. From the photographs it can be seen that the particle size of the smoke from Bessemer converters is predominantly smaller than 0.1 micron in diam. Additional data of this type will have to be collected before any definite conclusions will be drawn.

Visibility of Smoke

Clouds of particles of the same total weight but differing particle-size distribution can present deceivingly different appearances to the naked eye. This discussion is aimed at presenting a brief explanation of the reasons from such variations in appearance.

Smoke, as well as other visible objects, is seen because it differs from its surroundings in some way which can be detected with the eye. This contrast with the surroundings may be either a color contrast or a brightness contrast. Usually, both types of contrast are seen at the same time. The colors and the brightness of a cloud of smoke particles will vary with the relative positions of the light source or sources, the smoke cloud, and the observer.

When light strikes a cloud it may be transmitted, reflected, scattered, or absorbed by the particles in the cloud. Which of these phenomena occur or predominate depends on the sizes of the particles, on their refractive index relative to the surrounding medium, and on the wavelength of the light in the surrounding medium. Considering particles which are small relative to the wavelength of the light, that is, less than about 0.1 micron in diam, Rayleigh scattering occurs. Rayleigh's value for the intensity of light scattered at Angle β (with respect to the incident ray) is given by:

$$A^2 \frac{(D^1 - D)^2}{D^2} (1 + \cos^2 \beta) \frac{M\pi V^2}{\lambda^4 r^2},$$

where:

A is the intensity of the incident light
D^1 and D are the optical densities of the particles and the medium, respectively
M is the number of particles
λ is the wavelength
r is the distance of the scattering particle from the points of observation
V is the volume of the particle

Thus, scattering power is inversely proportional to the fourth power of the wavelength and, as a result, the smaller particles having a diameter much less than wave length (λ) tend to scatter blue light in preference to red. Smokes of these small particles appear blue by scattered light and the complementary red or yellow by transmitted light. Hence, power-plant plumes have a bluish cast in reflecting sunlight. However, when the sun is viewed through these plumes, they often have a light-orange appearance.

The scattering in the Rayleigh region increases as the sixth power of the particle diameter. As the particle diameter approaches and exceeds the same magnitude as the wavelength of light, the reflection and refraction of the light become increasingly important and scattering becomes less important. When the circumference of a particle is equal to the wavelength of the illumination (0.17 micron for $\lambda = 0.546$ micron), light is scattered almost equally in all directions by a single particle, the beam traveling in the same direction as the incident beam being two times as strong as that at right angles. On the other

of a Typical Bottom-Blown Acid Bessemer Converter

the Tip of the Flame

Smoke Composition, %									
NiO	Cr_2O_3	CuO	PbO	SnO	TiO_2	Co_2O_3	B_2O_3	Ag_2O	Remarks
0.02	0.07	0.02	0.05	0.1	0.02	<0.01	N. D.	t	
0.01	0.02	0.02	<0.02	<0.02	<0.02	<0.01	N. D.	N. D.	Gain on ignition, +2.1%
0.01	0.04	0.02	<0.02	<0.02	0.04	<0.01	0.08	t	
0.01	0.04	0.04	<0.02	<0.02	0.04	<0.01	0.08	t	
0.02	<0.02	0.02	<0.02	<0.02	0.04	<0.01	N. D.	N. D.	Includes dust from blowing tuyères on new bottom before turnup
0.06	0.06	0.04	<0.02	<0.02	0.06	<0.01	N. D.	N. D.	
0.02	0.06	0.05	0.02	<0.02	0.08	<0.01	<0.05	t	
0.05	0.06	0.05	0.02	<0.02	0.06	<0.01	<0.05	t	
0.02	0.02	0.02	<0.02	<0.02	<0.02	<0.01	N. D.	t	Gain on ignition, +1.7%

der by difference.

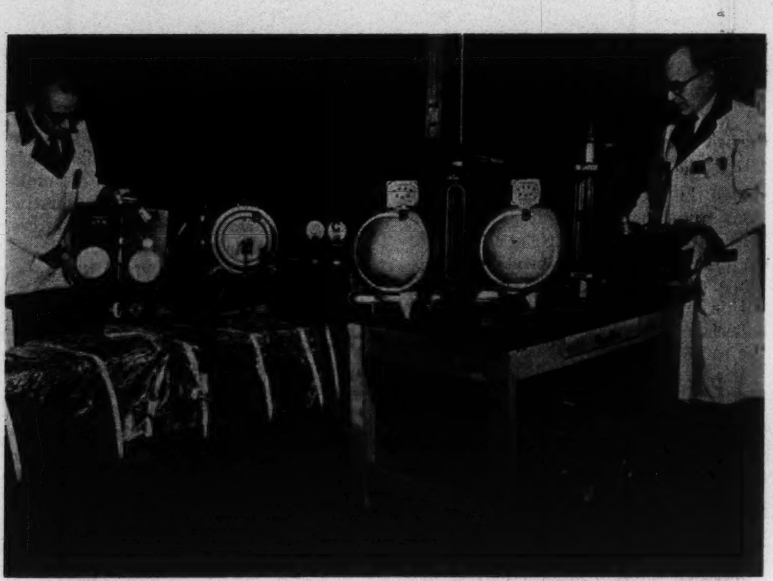

Fig. 3. Exhaust duct and sampling equipment for laboratory converter. (a) AISI smoke sampler; (b) flow meters; (c) smoke meter instruments; (d) portable electrostatic precipitator power pack and probe; (e) thermocouple for stack temperature; (f) filter paper holder; (g) vacuum pumps; (h) exhaust duct.

hand, for a similar particle three microns in diam the continuing beam is 100,000 times as strong as that at right angles. At the same time, the total amount of light scattered at 90 degrees is about 500 times as great for the larger particle. The volume of the larger particle is, however, about 27,000 times as great as the smaller one. Thus, if the volume of material in the three-micron particle were to be divided into particles 0.1 micron in diam, the total amount of light scattered by these particles would be 50 times as great as for the single particle.

The scattering effects discussed above are those observed for dielectrics without appreciable absorption in the visible range of the spectrum. In cases where absorption occurs, the visual appearance of the smoke can be changed considerably. The apparent absorption of a cloud viewed by transmitted light is actually a combination of true absorption and scattering. Absorption results when the frequency of the light wave is equal to the natural frequency of some elastically bound charged particles in the absorbing material. The energy absorbed in this resonating system may result in heat motion in the absorbing material or it may be given off at other wavelengths which may or may not be visible. Thus, the absorbed energy may produce heat, fluorescence, or selective reflection. The energy absorbed by resonance may also be given off at the resonant wavelength.

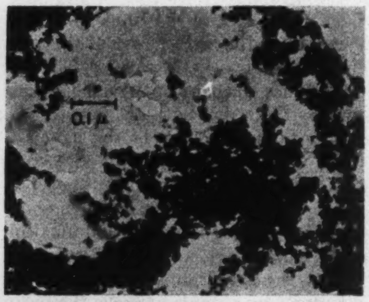

Fig. 5. Electron photomicrograph of particles collected while blowing with air and 20 cfm hydrogen and the blast gas enriched to 23% oxygen.

Absorption Changes Color

True absorption, that which results in heat, changes the color of the cloud, the resulting color depending on the specific wavelengths absorbed. Fluorescence, selective reflectance, and resonance radiation also change cloud color and may result in color differences, depending on whether the cloud is viewed by reflected or transmitted light.

The presence of metallic particles in the cloud will result in still more complex behavior with respect to visual appearance. This is because the optical properties of the metals are quite different from those of dielectrics.

In the above discussion the effects of clouds on polarization of light have been neglected because these effects cannot be observed with the naked eye. Also, Raman scattering has not been considered because it is weak.

This is a limited discussion of a most complex phenomenon. Even though the theory of the various scattering and absorption effects is fairly well known, any calculation of the total effect in a specific case would be extremely complicated and laborious

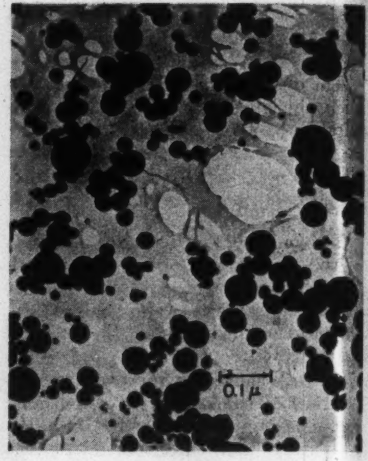

Fig. 4. Electron photomicrograph of particles collected while blowing with air enriched to 23% oxygen.

Smoke Intensity from Laboratory Converter

A photoelectric smoke meter was used to measure the changes in smoke density. With this instrument, the effect on smoke of additions to the blast gas or into the nose was immediately evident. The meter consisted of a six-volt lamp powered by a constant-output voltage transformer and a photoelectric cell whose output was fed to a recording potentiometer which indicated changes in smoke density. Smoke was withdrawn from the stack above the vessel and was passed through a 30-in. column through which the lamp and photoelectric cell were sighted.

To provide a permanent sample of the smoke and to augment the photoelectric smoke record, an AISI smoke meter was also used for smoke density analysis. An AISI smoke meter is an instrument for measuring smoke density. A known volume of gas containing smoke or dust is drawn through a filter paper. By a timing mechanism, the paper is automatically moved and a new sample is collected. Thus, a time record of smoke intensity is made. The filter paper spots are later evaluated by light trans-

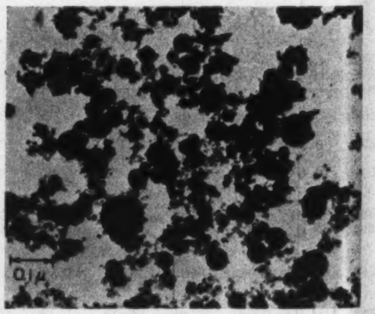

Fig. 6. Electron photomicrograph of particles collected while blowing with air and 20 cfm hydrogen and the blast gas enriched to 24% oxygen.

mission through the dust spot which is measured by a photoelectric cell. Throughout the test, samples which were 40 sec in duration were taken. These were followed by a five-sec interval during which the tape was manually moved. Percentage of light transmission through the samples was measured with the AISI spot evaluator. To obtain smoke density from the AISI spot evaluator, percentage of transmission was subtracted from 100. Thus, the AISI smoke-density curves and the photoelectric smoke-meter curves were similar. In general, the AISI smoke-meter density curves compared fairly well with those of the photoelectric smoke meter.

Figure 7 shows a typical photoelectric smoke-density meter record and AISI smoke-density meter record when blowing with air.

In all experiments, a sharp increase in smoke intensity was recorded near the end of the carbon blow. In the afterblow, smoke continued to be dense. In most experiments, when additives were introduced to the blast-gas steam, the heats were slightly overblown to note more effectively the changes produced in the smoke. These changes were especially pronounced when hydrogen, methane, ammonia, or steam was added to the blast gas.

Exhaust-Gas Composition

Exhaust-gas samples were collected from inside the converter not only to determine the relationship of gas composition to the blowing cycle but also to obtain information which would be helpful in the analytical approach to smoke formation.

The sampling apparatus consisted of a standard $^1/_8$-in. steel-pipe sampling probe and glass bottle connected through a pet cock and vacuum-hose arrangement. One end of the steel probe was closed with a thin zinc sheet soldered to the end. The entire assembly was evacuated to between 20 and 25 microns of pressure. The sample was collected by inserting the zinc-covered end of the sampling probe into the vessel and allowing it to melt. Before the probe was removed from the gas stream, the connecting pet cock between the glass sample bottle and the steel probe was closed, thereby preventing any air from entering the bottle. The samples were analyzed in an Orsat gas analyzer. A number of samples were also analyzed in the mass spectrometer. Both methods showed good agreement.

Figure 8 shows typical CO and CO_2 content in the exhaust gas inside the converter during a heat blown with air only. During the silicon blow, the CO averaged approximately 3% and the CO_2 averaged approximately 15%. During the carbon boil, the CO rose to about 28% and the CO_2 decreased to approximately $3^1/_2$%. As the gases leave the converter, all the CO burns to CO_2.

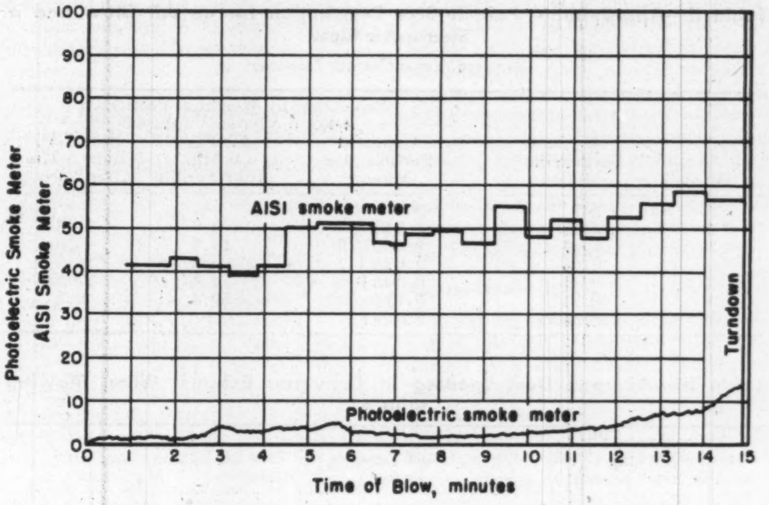

Fig. 7. Typical photoelectric smoke density meter and AISI smoke density meter records when blowing with air.

From exhaust-gas samples taken during the carbon blow, the material balance of oxygen was usually satisfied. During other parts of the blow when slag was being formed, the oxygen material balance was not satisfied.

Gaseous Blast Gas Additives

In commercial practice, steam is frequently added to the blast gas to reduce the metal temperature in the vessel. CO_2 is added to the blast gas in certain types of Bessemer converters to produce low-nitrogen steels. Both of these gases react with iron and carbon and cool the bath because the reactions are highly endothermic. When steam is added in sufficient quantity, smoke from the vessel is suppressed. However, when CO_2 is added to the blast gas in full scale operations, a similar reduction in smoke does not occur. This was confirmed by a brief trial with CO_2 in the laboratory converter. Thus, it was reasoned that hydrogen might have some effect on smoke suppression.

Effect of Hydrogen in Blast Gas

To investigate this effect, hydrogen was injected into each of the 20 $^1/_8$-in. tuyère holes through $^3/_{64}$-in. diam hypodermic tubes which extended two in. into the tuyères. This method of hydrogen addition to the blast was used for safety reasons.

A decided decrease in smoke was recorded on the photoelectric smoke meter when approximately 25 cfm of hydrogen was added to the blast gas consisting of 120 cfm of air enriched to 23% oxygen. This phenomenon occurred in nearly every test in which hydrogen was used. The hydrogen was usually added near the end of the blow when the smoke discharge was moderately heavy. Figure 9 shows the effect of hydrogen on smoke suppression.

To determine whether hydrogen suppressed smoke simply by diluting the blast gas, duplicate tests were made with hydrogen and with helium. In these tests, the air for the blast was reduced in order to reduce the nitrogen content of the blast gas by the equivalent volume of hydrogen or helium which was to be added. Additional oxygen was supplied to make up a net blast gas of 123 cfm enriched to 23% oxygen. With helium as part of the blast gas, smoke was not suppressed. During one heat, the

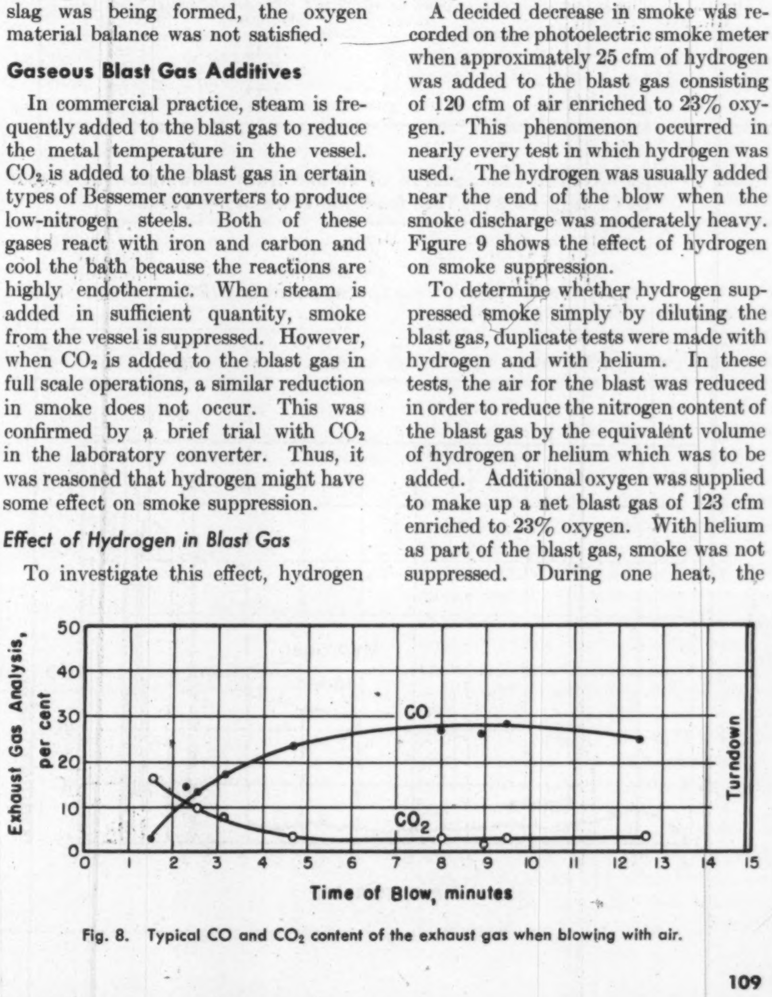

Fig. 8. Typical CO and CO_2 content of the exhaust gas when blowing with air.

Table II—Approximate Particle-Size Distribution for an Air Blow and a Steam-Air Blow

Sampled with a Cascade Impactor

Stage	Average Particle Size, Microns	Percentage by Weight of Particles Below 5 Microns Captured: Captured Particle Size, Microns	Air Blow 9 Min After Turnup	Steam-Air Blow 5 Min After Turnup
1	>5	>5	—	—
2	3.38	2.5 to 5	9.9	11.3
3	1.67	1.2 to 2.5	13.1	46.8
4	0.85	0.6 to 1.2	9.8	9.9
5	0.42	0.3 to 0.6	16.4	22.5
6	0.21	0.15 to 0.3	50.8	9.5
—	Smaller	Smaller	?	?

Table III—Average Dust Loading in Converter Exhaust When Blowing with Air

Approximate Time During Blowing Cycle, Min After Turnup	Dust Loading per 1000 Lb Exhaust Gas, Lb: Average	Minimum	Maximum
1–3	0.55	0.08	1.49
3–6	0.40	0.08	0.83
6–9	0.52	0.04	1.54
9–12	0.57	0.06	1.97

Table IV—Average Dust Loading in Converter Exhaust Gas When Blowing with Enriched Air

22 to 24% Oxygen

Approximate Time During Blowing Cycle, Min After Turnup	Dust Loading per 1000 Lb Exhaust Gas, Lb: Average	Minimum	Maximum
1–3	0.98	0.45	1.80
3–6	0.78	0.36	2.19
6–9	1.15	0.44	2.66
9–12	1.25	0.51	2.79

Table V—Approximate Composition of Smoke from a Commercial Vessel as Compared with That from the Laboratory Vessel

	Beginning of Blow, 3 to 6 Min After Turnup			Middle of Blow, 6 to 9 Min After Turnup			End of Blow, 9 Min to Turndown		
Vessel	Fe_2O_3, %	SiO_2, %	MnO_2, %	Fe_2O_3, %	SiO_2, %	MnO_2, %	Fe_2O_3, %	SiO_2, %	MnO_2, %
Commercial	96	3	1	94	4	2	90	7	3
Laboratory	70	20	10	60	25	15	50	30	20

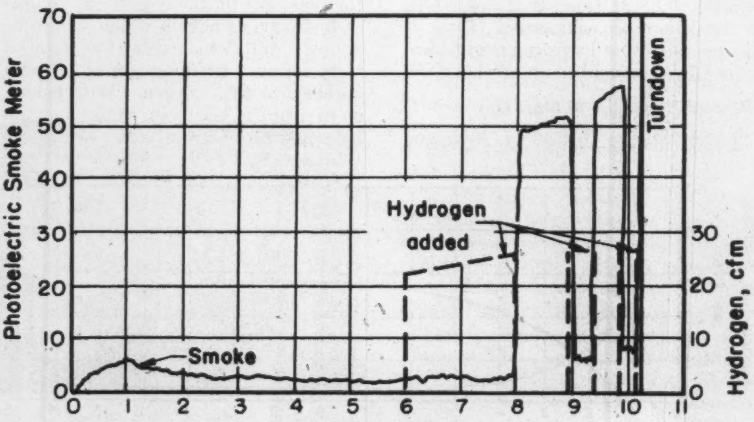

Fig. 9. Effect of hydrogen on smoke suppression.

helium and the hydrogen were alternately introduced several times near the end of the blow. As before, smoke discharged during the hydrogen addition was much less than when helium was added.

Although the flame visually appeared long and more yellow with a hydrogen blast than with an air or an oxygen-enriched air blast, the total radiation intensity of the flame, as recorded in the flame-intensity recorder, decreased.

From the AISI smoke-density recorder, the average smoke density was 35 when hydrogen was part of the blast gas. With helium as part of the blast gas, and with air enriched to 23% oxygen, the average smoke density was 50. Although it is not conclusive, this indicates that less smoke was discharged when hydrogen was used as part of the blast gas.

Dust samples collected on the filters in the stack above the converter indicated that during addition of hydrogen to the blast gas, dust loading of the effluent gases was somewhat lower than when helium was used as part of the blast or when air enriched to 23% oxygen was blown through the metal. Table VI shows the approximate exhaust-gas dust loading from the laboratory converter when blowing with 123 cfm of blast gas. Because of the short blowing period of the laboratory converter, only a few dust samples could be taken and, consequently, firm conclusions should not be drawn from these results.

Observations of the flame with a hand spectrascope showed a change from a continuous spectrum to a discontinuous spectrum. This indicated that during the addition of hydrogen to the blast gas, the discharge of incandescent particles decreased.

Steam Addition to the Blast Gas

To investigate the effect of steam on smoke suppression in the laboratory converter, several tests were made in which steam was introduced into the blast-gas stream. In commercial practice, to cool a melt which is excessively hot, approximately 233 lb/min of steam is introduced into a blast-gas stream of approximately 25,000 cfm. This amounts to 0.93 lb of steam/100 ft^3 of blowing gas. In field tests conducted on a commercial vessel, smoke was suppressed by introducing 8.2 lb of steam/min into a blast air stream of approximately 25,000 cfm. This amounts to 0.33 lb of steam/100 ft^3 of blast air.

In an initial attempt to suppress smoke on the laboratory converter, 0.14 lb of steam/100 ft^3 of blast was introduced into a blast air stream of 120 cfm which was enriched to 22% oxygen. At the end of the carbon

Table VI—Approximate Exhaust-Gas Dust Loading from the Laboratory Converter

When Blowing with Approximately 123 cfm of Blast Gas

Heat	Blowing-Gas Conditions	Dust per 1000 Lb of Exhaust Gas, Lb
49	Air + 20 cfm of H_2 enriched to 23% O_2	0.41
50	Air + 20 cfm of H_2 enriched to 23% O_2	0.45
51	Air + 20 cfm of H_2 enriched to 23% O_2	0.60
52	Air + 20 cfm of He enriched to 23% O_2	0.64
53	Air enriched to 23% O_2	0.91
54	Air + 20 cfm of H_2[a] enriched to 28% O_2	0.80

[a] Total blast gas was approximately 135 cfm.

blow, smoke increased slightly. During the afterblow, the steam was turned off and a marked increase in smoke resulted. During the afterblow, while the steam was on, dust loading in the exhaust gas increased from approximately 0.556 lb of dust/1000 lb of exhaust gas to an average of approximately 1.11 lb of dust/1000 lb of exhaust gas.

In a later test, the addition of 1.05 lb of steam/min to 94 cfm of blast air enriched to 24% suppressed the smoke during the carbon blow. When the steam was turned off, the smoke intensity immediately increased. This was shown both on the photoelectric smoke meter and on the AISI smoke meter.

Effect of Other Hydrogenous Gases

Because of the cost and the danger from explosion with hydrogen, the effects of two other hydrogenous gases were determined: methane and ammonia. In both cases they were added in amounts sufficient to give the same rate of hydrogen as with molecular hydrogen. The smoke reduction obtained with both methane and ammonia in the blast gas was nearly as complete as with hydrogen.

The results obtained with these additives are, of course, quite promising. Additional research both on the laboratory converter and on a bench-scale crucible is planned to determine the mechanism of smoke abatement at the source.

Adding Hydrogen, Methane, and Steam into the Nose of the Converter

Hydrogen, methane, and steam were separately added into the nose of the vessel for two reasons: (1) to determine their effect on smoke reduction and (2) to attempt to determine whether the hydrogen added into the blast gas caused the smoke suppression in the metal bath, in the gas above the bath, or in the emergent flame. The additive gases were injected into the flame through an 18-in.-long ceramic-coated lance during the latter part of the blow when the smoke was comparatively dense.

When hydrogen in the amount of 22 to 28 cfm was added into the nose of the vessel, no noticeable decrease in smoke was observed or recorded on the photoelectric smoke meter. During the addition, the vessel was blown with 112 cfm of air enriched to 24%. The flame intensity as recorded on the flame meter increased approximately twofold because of the hydrogen burning. Spectrographic observation indicated no change from the continuous spectrum which had been observed before the hydrogen was added.

When 14.3 cfm of methane was added into the nose through the ceramic-coated lance, no noticeable change in smoke was observed or recorded on the photoelectric smoke recorder. The flame intensity increased greatly when the methane was added. Spectrographic observation of the flame showed a continuous spectrum, indicating a continued ejection of incandescent particles.

In a further attempt to eliminate smoke from the converter, steam was added into the nose of the vessel through the 18-in.-long lance. When 1.05 lb of steam/min was introduced into the nose, a slight decrease in smoke was recorded on the photoelectric smoke recorder.

Sodium Chloride Addition

Dautrebande, et al.,[12] have stated that sodium chloride solutions promote agglomeration of submicron particles. In an attempt to increase the size of the smoke particles by providing nuclei on which to grow and agglomerate, one lb of NaCl in the form of rock salt was dropped into the nose of the vessel during a blow. Smoke volume and intensity increased manyfold, and dust collected at the stack sampling station was between five and ten times as much as that normally captured when blowing with similar conditions.

Flame Intensity

In the operation of a Bessemer converter, the end of the blow is accompanied by a sharp drop in the length and intensity of flame leaving the vessel, at which time the vessel is normally turned down. To facilitate the operation of the laboratory converter, a flame-intensity recorder was utilized. It consisted, essentially, of a photoelectric cell focused on the flame a short distance above the converter nose. A recording potentiometer measured the output of the cell.

During the beginning of the blow when silicon was being oxidized, the flame intensity was usually low. As the carbon blow began, the flame intensity gradually increased. When the carbon was practically all oxidized, the flame dropped rapidly, indicating the end of the blow. When hydrogen or steam was added to the blast gas, the flame drop was not distinct. This was apparently caused by the hydrogen burning in the flame above the vessel. As discussed elsewhere, the hydrogen did not burn in the vessel.

Composition of Smoke Inside the Converter

Information on the state of smoke particles as they leave the converter and before they are oxidized is important in the analysis of smoke formation. This knowledge should enable a better understanding of its generation and, possibly, its subsequent suppression or agglomeration.

To obtain this information, particulate samples were taken from inside the converter through a water-cooled stainless steel probe. The probe was inserted approximately 12 in. into the nose of the vessel. The particles were collected on a Fiberglas filter which was mounted in a gas-tight filter holder. Prior to collecting the sample, the filter holder and sampling probe were purged with argon to remove oxygen. To prevent oxidation of the particles after collection, the samples were retained in a nitrogen-atmosphere dry box.

Table VII shows the analysis of samples taken from inside the converter. Analysis for Fe, Fe^{++}, and Fe^{+++} was made by wet chemical techniques, and iron was determined

Table VII—Analysis of Samples Taken from Inside the Converter

Heat	49	50	51	53	54
Blowing-gas additives	H_2-23% O_2	H_2-23% O_2	He-23% O_2	Air-23% O_2	H_2-28% O_2
Time of blow after turnup, min	4–8	5–7	5–7	1–3	4–8
Analysis, %					
Fe(Fe)	1.9	3.5	4.1	9.1	4.9
FeO (Fe^{++})	19.2	16.8	15.7	28.3	32.6
Fe_2O_3 (Fe^{+++})	0.7	2.5	2.9	3.5	0.5
SiO_2	31.3	77.2	77.3	59.1	62.0
MnO_2	45.0				
Other	1.9				

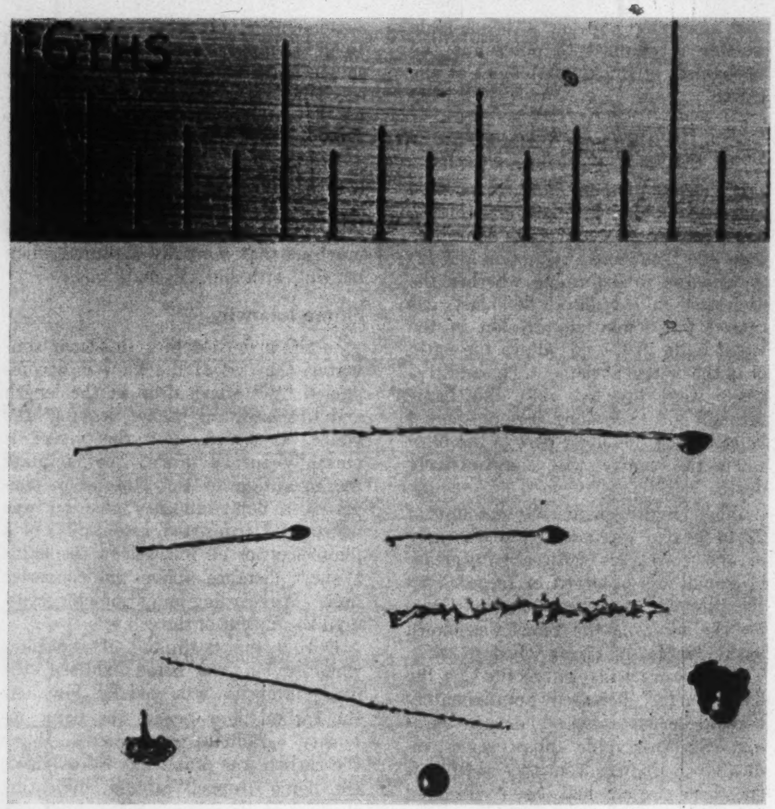

Fig. 10. Typical particles of metal collected in the filter holder while taking smoke samples from inside the converter.

either colorimetrically or volumetrically. Analyses for silicon, manganese, and other constituents were made by the emission spectrography. The possibility exists that some of the Fe^{++} obtained by chemical analysis was dissolved from minute particles of $2 FeO \cdot SiO_2$ which might have been collected on the filter. These data indicate that the iron dust particles inside the converter are largely FeO with smaller amounts of Fe and Fe_2O_3.

In dismantling the filter holder in the dry box, small pieces of metal in the form of needles and balls were found. Figure 10 shows typical examples of this material. It was initially believed that these were pure iron crystals. However, on examination after polishing and etching, the presence of carbon in the grain boundaries precluded this supposition. The particles might have been metallic ejections from the metal bath which found their way through the sampling probe. They were not included in the analysis of the dust on the filter.

Metal-Temperature Measurements

Smoke from a steel process is generally associated with high metal temperatures. In the Bessemer converter process, smoke increases during the blowing cycle, as does the temperature of the metal. To evaluate the relationship of metal-bath temperature to the amount of smoke discharged from a Bessemer converter, several unsuccessful attempts were made to measure metal-bath temperature throughout the blow. Because accurate and consistent temperature data were not obtained, a correlation between smoke emission and metal temperature could not be made. During charging and tapping, optical pyrometer temperature measurements were taken while pouring.

Turnup and Turndown

The principal effort to date has been concentrated on the reduction or elimination of smoke from the Bessemer converter while in the upright position. When a reasonable solution has been found to this portion of the problem, efforts will be directed toward the elimination of the smoke which is emitted when the vessel is turned up to a vertical position for blowing and at the end of the blow when it is turned down for pouring.

Acknowledgments

The Task Force supervising this research is composed of W. M. Frame, Chairman, De Yarman Wallace, Dr. W. H. Jukkola, Dr. S. T. Jazwinski, and W. D. Spaulding. The Task Force is a part of the over-all AISI Air Pollution Control Committee of which the Chairman is W. O. Everling. The counsel of the members of the Task Force to the research staff has been effectively supplemented by valuable advice and generous assistance from experienced operating personnel from the steel industry. Acknowledgment is also made to A. W. Thornton, J. N. Hornak, and J. H. Richards for their many helpful suggestions in this work, and to the operating and research personnel of the National Tube Division, U. S. Steel Corp., for their cooperation and assistance during the temperature measuring and smoke sampling tests.

Battelle staff advising and consulting on the work have included C. E. Sims, Technical Director, R. A. Sherman, Technical Director, H. M. Banta, formerly Consultant, now Assistant Director of Research and Technology, National Tube Division, United States Steel Corp., N. H. Keyser, metallurgist, G. W. P. Rengstorff, Assistant Chief Physical Metallurgy, A. Levy, Assistant Chief, Physical Chemistry, and R. B. Engdahl, Division Chief.

REFERENCES

1. H. Kosmider, H. Neuhaus, and H. Kratzenstein, "Exhaust Gas Conditions in the Basic Bessemer Steel Mill With the Use of Various Refining Gases," *Stahl und Eisen*, **74:** 17, 1045–54 (1954). (English translation.)
2. W. Dehne, "Possibilities for Removing the Dust From Brown Converter Waste Gases," *Stahl und Eisen*, **77:** 1 553–62 (1957). (English translation.)
3. R. Meldau, and D. Laufhütte, "Particle Size of Brown Smoke From Oxygen Converter," *Archiv. für das Eisenhüttenwesen*, **27:** 3, 149–52 (1956). (H. Brutcher Translation No. 3770.)
4. G. S. Sel'kin and N. I. Zadalya, "Prevention of Brown Fumes When Blowing Oxygen Through Steel Baths," *Stal*, **17:** 10, 884–87 (1957). (H. Brutcher Translation No. 4056.)
5. W. Pepperhoff and C. Passov, "Optical Properties of Iron Oxide Fumes," *Archiv. für das Eisenhüttenwesen*, Issue **2,** 77–82 (Feb. 1958).
6. P. K. Gledhill, P. J. Carnall, and K. H. Sargent, "Oxygen Lancing of Pig Iron and Subsequent Fume Treatment With a Pease-Anthony Venturi Scrubber," *J. Iron and Steel Institute*, pp. 198–210 (June 1957).
7. B. Kalling, F. Johannson, and L. Lindskog, "The Use of Oxygen-Carbon Dioxide Instead of Air in the Final Stage of a Basic Bessemer Process," *J. Iron and Steel Institute*, **168,** 337–43 (Aug. 1951).
8. K. Mayer, H. Knüppel, and H. J. Därmann, "Refining Thomas Pig Iron With Carbon Dioxide-Oxygen Gas Mixture," *Stahl und Eisen*, **72:** 23, 1409–17 (1952).
9. G. Naeser, W. Pepperhoff, and H. Riedel, "Summary of Observations Through the Bottom Tuyères of a Blasting Converter," *Stahl und Eisen*, **75:** Part 2, 1244–50 (1955).
10. E. J. Kohlmeyer and H. Spandau, "On the Gasification of Iron,"

Archiv. für das Eisenhüttenwesen, **18:** 1, 3–6 (1944–1945).

11. S. T. Jazwinski, "Spectrographic Control of the Converter Blow," *Iron Age* (May 1947).
12. L. Dautrebande, H. Beckmann, and W. Walkenhorst, "New Investigations on Agglutination of Fine Dust Particles by Means of Sodium Chloride Aerosols and Considerations on Fine Dusts Problem," *Industrial Hygiene Digest,* **18:** 1, p. 25 (Jan. 1954).
13. J. M. Pilcher, R. E. Thomas, and P. I. Mitchell, "The Cascade Impactor for Particle-Size Analysis of Aerosols," Proceedings 42nd Annual Meeting of CSMA (Dec. 6–7, 1955).

Bibliography

The following literature has not been referred to in this paper, but has been reviewed and judged to be of value on this subject.

L. V. Bogdandy, "Study of the Simultaneous Processes of Droplet Nuclei Formation and Droplet Size Increase as Illustrated by the Dust Formation During Pneumatic Steel Refining," *Zeitschrift für Elektrochemie,* **61:** 1, 222–26 (1957).

R. M. G. Boucher, "The Coagulation of Industrial Aerosols by Ultrasonics," *Génie Chimique,* pp. 163–73 (June 1957).

P. Coheur and H. Kosmider, "Enriched Blast in Basic Steelmaking," *Metal Progress,* pp. 67–72 (Jan. 1957).

O. Cuscoleca, F. Narbeshuber, F. Grohs, F. Wegscheilder, K. Rosner, and W. Kuhnelt, "Process and Apparatus for the Cleaning of Converter Exhaust Gases," Austrian Patent No. 189, 171, Issued Mar. 11, 1957. Issued to Alphine Montangesellschaft, Vienna, Austria.

W. A. Fischer and M. Wahlster, "Basic Experimental Converter With a Continuous Bath Temperature Measurement and End Point Determination," *Stahl und Eisen,* **78:** 10, 646–54 (1958).

R. Graef, W. Dick, and L. V. Bogdandy, "Rotor Steelmaking Process," *Journal of Metals,* pp. 1435–39 (Nov. 1957).

K. Guthmann, "The Dust Problem in Steel Works," *Stahl und Eisen,* **73:** 23, 1515–24 (Nov. 5, 1953).

P. Höller and H. Smit, "Optical Method of Determining the Course of Temperatures When Refining Steel in the Converter," *Stahl und Eisen,* **78:** 12, 799–804 (June 12, 1958).

B. Kalling, and F. Johansson, "The 'Kaldo' Rotary Oxygen Steelmaking Process," *Iron and Coal Trades Review,* pp. 1497–99 (Dec. 21, 1956).

R. Kemmetmuller and R. Rinesch, "Treating Converter Waste Gases," U. S. Patent 2,831,762. Assigned to Waagner-Biro Aktiengesellschaft, Vienna, Austria.

C. E. Sims and F. L. Toy, "Operation of a Basic-lined Surface-blown Hearth," *Journal of Metals,* Trans. AIME, **188,** 694–708 (April 1950); 1350–52 (Nov. 1950).

S. Vajda, "Open-Hearth Dust Control," *Iron and Steel Engineer,* pp. 111–20 (July 11, 1952).

F. Wever, W. Koch, H. Ludering, H. Knuppel, K. E. Mayer, B. A. Steinkopf, and G. Wiethoff, "Investigation of Converter Smoke in Conjunction with the Spectrometric Control of the Thomas Converter," *Stahl und Eisen,* **77:** 21, 1451–59 (1957).

A. Weyel and H. Kosmider, "Metallurgy and Practice of the Basic Converter Processes," *Blast Furnace and Steel Plant,* pp. 1039–45, 1065 (Sept. 1954); pp. 1162–68 (Oct. 1954).

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The Role of ENGINE BLOWBY *in* AIR POLLUTION*

ANDREW H. ROSE, JR. and RALPH C. STAHMAN, Robert A. Taft Sanitary Engineering Center, Division of Engineering Services, U. S. Department of Health, Education, and Welfare, Cincinnati, Ohio

The significance of crankcase hydrocarbon emission as a major factor in the over-all hydrocarbon emission from the automobile has recently been reported.[1] In contrast, earlier work[2] covering the concentration of hydrocarbons and oxygenated hydrocarbons in the blowby and exhaust gases indicated that crankcase emissions were not a significant source of air pollutants. However, with the recent report that crankcase or blowby emissions account for 40% of the total hydrocarbon emission of the automobile, exclusive of carburetor vent losses, interest has again been aroused as to the significance of this problem.

In order to substantiate the more recent studies and due to the possible importance of this emission source from a national standpoint, a study was undertaken by the Public Health Service. This report covers the results of a survey of 13 late model cars in which measurements were made of the concentration and quantity of both crankcase and exhaust gas emissions during various modes of vehicle operation.

Equipment and Procedures

The test vehicles used in the blowby evaluation were a group of employee-owned cars on which the actual mileage could be verified. The 13 vehicles tested included both sixes and eights, ranged in age from one to five years, and had road mileages varying from 7000 to 43,000 miles (Table I). Products of General Motors Corporation, Ford Motor Company, and Chrysler Motors Corporation were tested.

Road conditions were simulated by operating the test vehicles on a hydraulic power absorption type chassis dynamometer. Four operating conditions investigated, each at 20, 30, and 40 mph were, first, road load cruise; second, engine loads simulating moderately heavy continuous acceleration; third, engine loads simulating light continuous deceleration; and, fourth, heavy deceleration at closed throttle. The fuel used for all tests was a 20 bromine number reference fuel prepared by Western Oil and Gas Association for use in air pollution research programs. All tests were made after the engine and crankcase temperatures had stabilized at road conditions.

Cruise road loads were duplicated by setting the power absorption of the dynamometer at specified levels for the 20, 30, and 40 mph speeds. The levels used had been established previously in a series of road tests, based on actual engine manifold vacuums at given engine speeds. One power absorption setting was used for each road load cruise condition for all vehicles tested. The acceleration condition for each of the three test speeds was produced by establishing the dynamometer load at levels so that the engine manifold vacuum for the acceleration under study was one-half that for the road load cruise value at the same speed. Light decelerations at part throttle were obtained by operating the vehicle out of gear at engine rpm's equivalent to the three test speeds. Previous findings of negligible emissions from the heavy deceleration conditon were confirmed by motoring four test vehicle engines with closed throttle at the three test speeds.

Measurements were made for CO, CO$_2$, and hydrocarbon concentrations of both the exhaust and crankcase vent gases. Samples were continuously withdrawn from the exhaust tailpipe and from the flow measurement system attached to the draft tube of the crankcase and passed through Beckman L/B Model 15A nondispersive infrared analyzers in series (Fig. 1). CO and CO$_2$ concentration analyzers employed $^1/_4$- and $^1/_8$-in. sample cells respectively.

The analyzer used for exhaust and crankcase hydrocarbon concentration measurements was equipped with an acetylene-benzene-ethylene (ABE) sensitized detector and quartz optics. A 10$^1/_4$-in. sample cell was used for the measurement of both sources of hydrocarbons. To eliminate any response from carbon dioxide and water vapor in the sample stream, the analyzer was equipped with a 2$^1/_2$-in. filter cell charged with saturated CO$_2$. Due to the unequal response of the analyzer to various hydrocarbon types, the indicated concentration values are arbitrary numbers reading higher than the absolute hydrocarbon concentrations. Using a technique similar to that developed by General Motors[1] a correlation between ABE sensitized instru-

Fig. 1. Blowby metering system.

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* Presented at the 53rd Annual Meeting of APCA, Netherland-Hilton Hotel, May 22–26, 1960, Cincinnati, Ohio.

Table I—Test Vehicles

Test No.	Year	No. of Cylinders	Comp. Ratio	Displacement, In.^{3}	Mileage
1	1958	6	8.0	235	30,550
2	1957	6	8.0	235	33,523
3	1959	6	8.0	230	12,300
4	1957	6	8.0	235	7,408
5	1957	6	8.0	235	27,490
6	1957	8	8.6	272	25,236
7	1957	8	8.5	283	24,656
8	1957	8	8.0	265	36,690
9	1959	8	8.8	292	12,973
10	1955	8	8.5	324	42,430
11	1957	8	9.1	292	28,565
12	1955	8	8.5	324	43,370
13	1958	8	8.6	369	16,260

ment response and absolute hydrocarbon concentration was established for both the blowby and exhaust gases. All results shown in this report have been corrected to the absolute hydrocarbon concentration values Each set of nondispersive infrared analyzers was calibrated daily prior to testing.

Flow measurements of crankcase blowby volumes were accomplished using a precision venturi metering system (maximum over-all pressure drop 0.06 in. H_2O), connected to the draft tube of the crankcase (Fig. 1). The breather and dipstick tube of the crankcase were plugged, forcing all the blowby gases through the metering system. Due to the low over-all pressure drop in the system, no significant effect on blowby volume occurred. The metering system consisted of a water cooled condenser, water trap, venturi, and inlet temperature thermocouples. Pressure differentials across the venturi throat were measured using a precision micromanometer and flow volumes were corrected for temperature. The standard used to calibrate the venturi metering system was accurate to 0.5% which permitted blowby flow measurements to be accurate to 0.05 cfm.

The sampling system consisted of tailpipe and blowby aluminum sampling lines. water trap, filter, rotameter, pump, and analyzer. Exhaust gas concentrations were measured undiluted. Blowby concentrations, however, were measured after a dilution of 5.5 to 1 in a standard dynamic type dilution system using prepurified nitrogen as the diluent. The sampling systems were checked for leaks before and after each run.

Crankcase Emission Composition

A relative measure of the composition of blowby gases can be made on the basis of the percentage of carbureted fuel-air mixture and combustion products present in the blowby emission. Since no combustion occurs in the crankcase of the engine, the difference in CO_2 concentration between the engine exhaust and the blowby emission allows the computation of percentage of combustion products and of carbureted fuel-air mixtures in the crankcase emission. These calculations indicate that the mean blowby emission contains from 75 to 85% carbureted fuel-air mixture with the remainder combustion products. The data also indicate a possible trend in that the percentage of carbureted fuel-air mixture in the blowby emission increases with increasing engine load demand.

Since the composition of the blowby is predominantly from the carbureted fuel-air intake into the engine, the actual composition of the blowby emissions will be controlled by the composition of the fuel used in the vehicle. These findings are, in general, in agreement with those recently reported.

Crankcase Emissions

Due to the variation between vehicles tested, the data are presented as mean values of CO_2 and hydrocarbon concentrations, emission volumes, and gross hydrocarbon emission rates for both blowby and engine exhaust at each operating condition studied (Table II). The data are presented separately for six cylinder and eight cylinder engines with no differentiation between low and high mileage vehicles, since it was intended to test a sufficiently broad range of mileages to establish the emission trends.

There was a consistent decrease in blowby volume with increase in absolute manifold vacuum. To confirm this relationship, regression curves of the data for both six and eight cylinder engines are plotted in Fig. 2. While the variation between test vehicles is large, as indicated by the spread of the individual points, the high degree of correlation (0.85 for both six and eight cylinder engines) establishes this relationship as valid.

Table II—Crankcase and Exhaust Mean Emission Values

Operating Conditions			Test Measurements							
	Engine Condition		Crankcase Emissions				Exhaust Emissions			
Cycle	Inlet Manifold Vacuum	Air-Fuel Ratio	Volume, Cfm	Conc. HC, Ppm[a]	Pounds per, Hour[a]	Conc. CO_2, %	Volume, Cfm	Conc. HC, Ppm[a]	Pounds per, Hour[a]	Conc. CO_2, %
Cruise (road load)										
20 mph—6 cylinder	17.6	13.5	0.45	9530	0.044	3.0	15.3	1130	0.149	13.0
8 cylinder	20.0	12.9	1.10	8890	0.096	2.6	16.1	740	0.118	12.4
30 mph—6 cylinder	16.5	14.4	0.70	9370	0.065	2.5	28.4	670	0.189	15.0
8 cylinder	18.7	13.8	1.20	8400	0.100	2.5	27.1	640	0.170	12.5
40 mph—6 cylinder	13.6	14.0	0.95	8670	0.081	1.7	44.8	390	0.171	14.0
8 cylinder	17.1	13.8	1.55	8290	0.126	2.3	45.9	690	0.315	14.7
Acceleration (part throttle)										
20 mph—6 cylinder	8.8	—	1.05	8880	0.091	2.9	23.5	390	0.091	9.0
8 cylinder	10.0	12.9	2.30	7910	0.181	2.6	38.0	570	0.213	11.6
30 mph—6 cylinder	8.3	13.2	1.35	8660	0.116	1.9	44.8	650	0.293	10.3
8 cylinder	9.6	13.8	2.55	9580	0.243	2.2	63.3	730	0.456	12.2
40 mph—6 cylinder	6.9	14.1	1.55	8140	0.124	2.0	68.8	570	0.387	13.4
8 cylinder	8.5	13.8	2.75	8580	0.233	2.0	79.1	680	0.533	12.5
Deceleration (part throttle)										
20 mph—6 cylinder	20.3	12.6	0.25	9330	0.021	2.1	11.9	1180	0.139	11.3
8 cylinder	21.7	12.4	0.65	7550	0.048	2.1	12.9	1930	0.245	11.0
30 mph—6 cylinder	21.3	13.4	0.25	8350	0.021	2.5	13.3	1270	0.167	12.8
8 cylinder	22.2	12.6	0.80	7930	0.061	2.0	16.8	1450	0.241	12.1
40 mph—6 cylinder	21.8	13.9	0.45	7460	0.033	2.2	17.3	1090	0.187	14.1
8 cylinder	22.4	13.1	0.80	6930	0.056	1.8	19.2	1470	0.279	12.5

[a] Expressed as Hexane.

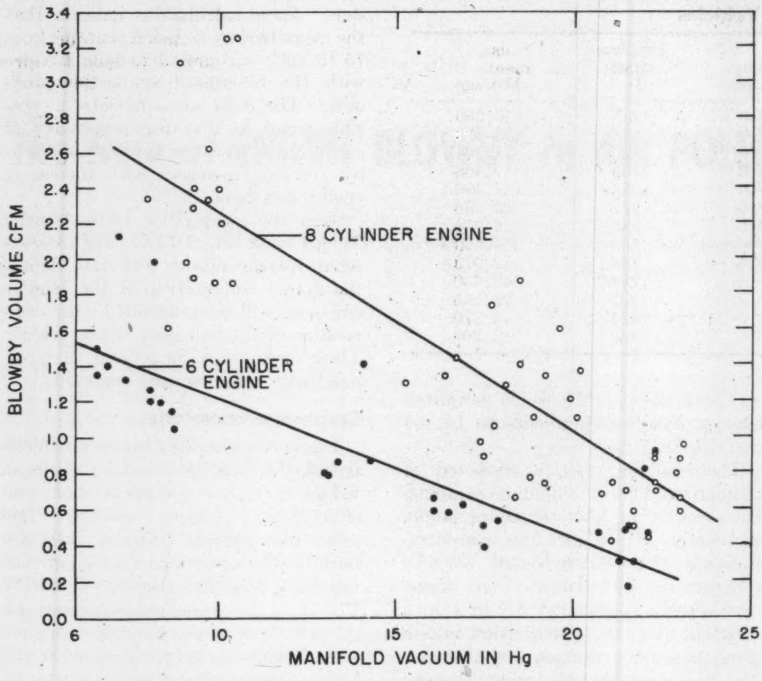


Fig. 2. Variation in blowby volume with manifold vacuum.

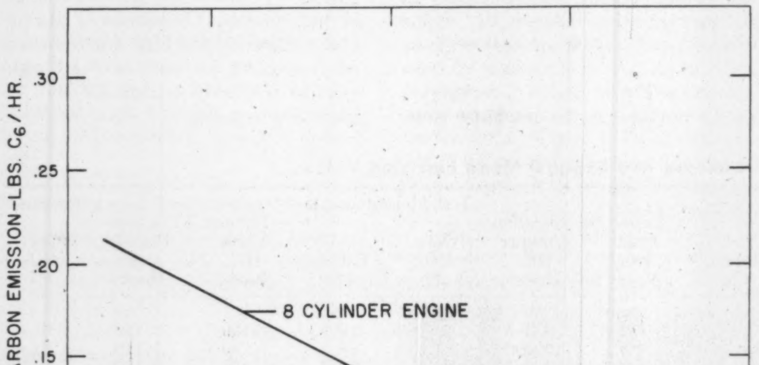


Fig. 3. Variation in blowby emission with manifold vacuum.

An attempt was made to evaluate the effect of vehicle speed independent of manifold vacuum by plotting each speed, i.e., 20, 30, and 40 mph, separately for the three manifold vacuum conditions of acceleration, cruise, and deceleration. No significant effect of speed independent of manifold vacuum was indicated.

Four test series were conducted at closed throttle deceleration conditions at the correspondingly higher manifold vacuums. In each case blowby volumes were essentially zero. This is confirmed in Fig. 2.

The data also indicate a consistent difference between blowby volume emission rates for the six cylinder and eight cylinder engines (Fig. 2). While evident from the regression curve that a limited degree of overlap of the individual data occurs between six and eight cylinder engines, the approximate twofold increase of the mean values of blowby volume for the eights over the sixes indicates a significant trend. This is substantiated by the high degree of correlation for the regression curves for both the six and eight cylinder engine emissions. This difference cannot be explained alone in terms of the increased circumferential blowby path around the pistons for the eight cylinder engine. An additional factor which may in part account for this difference is the higher average compression ratio of the eights over the sixes, i.e., 8.6 to 8.0. The higher compression ratio results in higher combustion pressure, hence a greater proportion of the cylinder charge is forced past the pistons.

The high concentration of hydrocarbons (expressed as hexane) in the blowby gases results from the high percentage of carbureted fuel-air mixture found in the blowby emission. There is little variation in concentration for the various engine operating conditions (Table II). However, the hydrocarbon concentrations in the blowby gases are from 10 to 20 times that in the exhaust gases.

As gross hydrocarbon emission rates are the product of blowby volumes and concentration, it would be expected that hydrocarbon emissions (expressed in pounds per hour) would follow the same general relationship as blowby volume. Regression curves for emission rate vs absolute manifold vacuum indicate this trend (Fig. 3). Gross hydrocarbon emissions decrease with increasing manifold vacuum, independent of the engine speed. As with the volumetric regression curves, the spread of the individual data, while not shown, is wide; however, since blowby concentrations were approximately constant for all tests, correlation coefficients for these curves are essentially the same as previously determined for blowby volumes, again substantiating the effect. Again the data indicate the generally higher emission rates for the eight cylinder engine as contrasted with the six, with essentially zero emission for both engine types at the low manifold vacuum associated with closed throttle deceleration.

To establish the relation of crankcase emissions to over-all automotive hydrocarbon emission, it is desirable to compare this source to the total automotive hydrocarbon discharge under projected driving conditions. For this purpose the driving cycle developed in the Los Angeles area by the Traffic Survey Panel of the Automobile Manufacturers Association was used. Using an appropriate percentage of time for each driving condition, exhaust and blowby gross hydrocarbon emissions (in pounds per driving hour) were calculated and the percentage of the total automotive emission resulting from blowby was determined. For six and eight cylinder engines respectively blowby accounted for 24 and 33% of the total automotive hydrocarbon emission, exclusive of carburetor vent losses. This percentage varied between 17 and 33% for the six cylinder engine and between 25 and 38% for eights.

Summary

Measurements of CO_2 concentration and flow rate have established that the composition of the blowby gas is approximately 75 to 85% carbureted fuel-air mixture. As such, the specific compositon of the crankcase gases will be controlled by the composition of the fuel used in the engine.

A high correlation was found between manifold vacuum and both blowby emission rate in cfm and gross emission in pounds per hour. Both factors decrease with increasing manifold vacuum resulting in substantially zero emissions at the low manifold vacuums associated with closed throttle deceleration. A further effect also apparent from the data is a twofold increase in crankcase emission rate and gross emission for the eight cylinder engine as compared to the six.

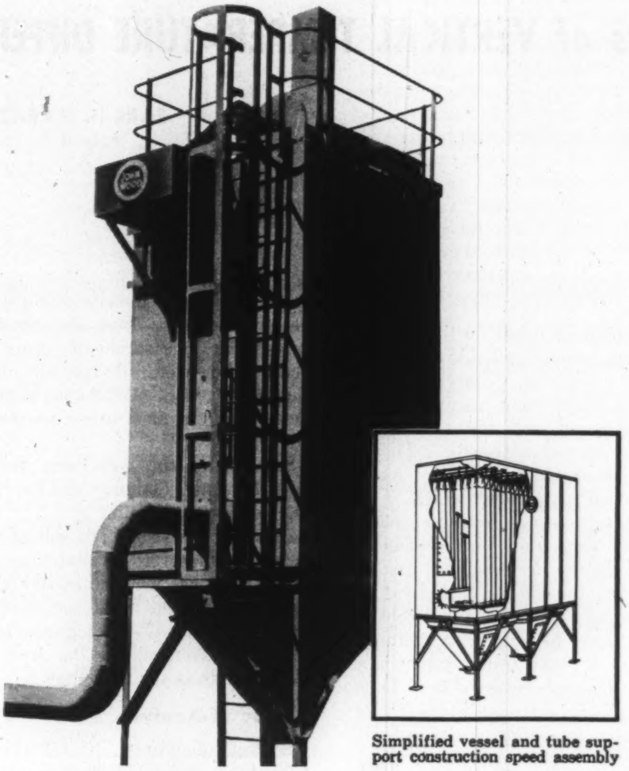
The effect of these variables for all driving conditions was based on the average driving cycle developed by the Traffic Survey Panel of the Automobile Manufacturers Association. It was found that crankcase emissions account for 24% of the over-all automotive emission for the six cylinder engine and 33% for the eights.

Acknowledgment

Acknowledgment is made of the contributions of K. L. Johnson, W. F. McMichael, T. J. Powers, and other members of the Auto Exhaust research group for their efforts in conducting the tests.

(*Continued on p. 144*)

New Ideas On Dust And Fume Control



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Effects of VERTICAL TEMPERATURE DIFFERENCE *on Soiling Index**

EARL H. MARKEE, JR., U. S. Weather Bureau Research Station,
Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio

A demand exists for the separation of natural and man-made effects on urban air pollution concentrations, the natural effect being mainly atmospheric dispersion and the man-made effect being the source strength. Therefore, it would be desirable to develop a meteorological parameter which is a function of total atmospheric dispersion using easily measurable meteorological elements. In the development of such a parameter, the effects of individual meteorological elements as predictors of air quality have to be investigated and evaluated. A prime consideration is a measure of atmospheric stability. Thus far, studies have been made of the effects of wind speed (an index of atmospheric stability) on urban particulate concentrations. Also, various multivariate analyses, including the effects of several other meteorological parameters on urban air quality, have been made.[1, 2, 3] Now, with some low-level urban vertical temperature difference measurements available, a more direct measure of atmospheric stability can be evaluated as a quantitative predictor of air quality.

This study utilizes vertical temperature difference measurements which have been made in the downtown area of Louisville, Kentucky. It is believed that these measurements are unique in that they are the only long period (July 1957 to present) measurements of free air temperature in the vertical available from the heart of an urban area, at least in this country. The temperature difference system has aspirated resistance thermometer units located at the 60-, 170-, and 524-ft levels of a television broadcasting tower and records the temperature difference between the 170- and 60-ft levels (ΔT_1) and between the 524- and 60-ft levels (ΔT_2). Also, a reference temperature at the 60-ft level is recorded.

Concurrent soiling index measurements were available from an AISI sampler located in the city, but approximately two miles from the television tower. The measurements from this location, however, are expected to show the same general trends as measurements made at most other locations in this urban area.

Samples of the data were selected from the winter (January and February, 1958) and summer (June and July 1958) seasons for analysis. The soiling index measurements were available as two-hour Coh/1000 feet values (C*), and the temperature difference measurements, ΔT_1 and ΔT_2, in degrees Fahrenheit, were averaged for the same two-hour periods as the C* values.

Method of Analysis

Scatter diagrams of C* vs the ΔT's have indicated that a straight line would provide a reasonably good fit to the data for analytical purposes. Therefore, simple linear correlation coefficients and the corresponding constants, *a*'s and *b*'s, of the regression equation $C^* = a + b\ \Delta T$ were computed for various data stratifications and averaging periods.

The data were first stratified by season in order to minimize the effects of seasonal source strength variations and to determine the gross seasonal effects of ΔT on C*. Also, 24-hour averages (06-06 CST) of the data were computed to see how well soiling index and vertical temperature difference are related when integrated over the entire diurnal cycle.

The data were further stratified into diurnal classifications so that the effects of diurnal source strength and meteorological variations, within groupings, would be minimized. A compromise was necessary in selecting the actual groupings of the two-hour periods so that the same groups could be used both in summer and winter. From these considerations, the following four diurnal classifications were selected:

22-06	CST	Night
06-10	CST	Morning transition
10-18	CST	Day
18-22	CST	Evening transition

After diurnal stratification of the data, the two-hourly values of C*, ΔT_1, and ΔT_2, for each day within each diurnal classification, were averaged to provide longer averaging periods (four or eight hour) in an effort to minimize the effect of random sampling variations and to describe the effects of longer sampling periods on the relationships. Both the two-hourly and the averaged data were used separately in the analyses to describe the effects of short and longer sampling periods on the relationships between C* and the ΔT's by diurnal classification.

In the process of averaging, by 24-hour and diurnal periods, if more than half of the two-hourly data for any one of the parameters was missing, the averaged data were eliminated from the calculations.

The means and standard deviations of the averaged data in their respective groupings were computed to serve as general indicators of the ranges of values upon which some of the physical and statistical interpretations of the regression and correlation analyses could be evaluated.

Results

The results of the regression and correlation analyses are shown in Tables I and II and the means and standard deviations of the averaged data are shown in Table III. In Tables I and II, *n* is the number of pairs of observations used in the calculations, *r* is the correlation coefficient, and *a* and *b* are the constants computed for the regression equation, $C^* = a + b\ \Delta T$, rounded to the nearest tenth. The ΔT_1's and ΔT_2's in Tables I and II are designators of the correlation and regression analyses of C* on ΔT_1 and C* on ΔT_2, respectively, for each of the classifications.

Some of the results that should be pointed out from Tables I and II are:

1 The correlation coefficients were found to be higher for averaged data than for two-hour data, with the ex-

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* Presented at the 53rd Annual Meeting of APCA, Netherland-Hilton Hotel, May 22–26, 1960, Cincinnati, Ohio.

Table I—Regression and Correlation Analyses of Averaged Data

Averaging Period	Winter n	Winter r	Winter a^a	Winter b^a	Summer n	Summer r	Summer a^a	Summer b^a
Night (8-hour)								
ΔT_1	52	0.72	2.7	1.7	53	0.44	1.6	0.6
ΔT_2	52	0.77	3.0	0.5	53	0.19	1.2	<0.05
Morning transition (4-hour)								
ΔT_1	53	0.43	3.5	1.3	53	0.14	1.5	0.2
ΔT_2	53	0.59	3.6	0.4	53	0.24	1.8	0.2
Day (8-hour)								
ΔT_1	53	0.27	2.7	0.9	53	0.24	1.4	0.2
ΔT_2	53	0.24	3.4	0.5	53	0.13	1.4	0.1
Evening transition (4-hour)								
ΔT_1	53	0.60	3.8	2.6	53	0.36	1.6	0.5
ΔT_2	53	0.75	4.4	0.8	53	0.31	1.6	0.2
Daily (24-hour)								
ΔT_1	53	0.64	3.3	2.0	53	0.41	1.7	0.5
ΔT_2	53	0.72	3.6	0.6	53	0.20	1.3	0.1

[a] In regression equation $C^* = a + b\,\Delta T$.

Table II—Regression and Correlation Analyses of 2-Hourly Data

Diurnal Group	Winter n	Winter r	Winter a^a	Winter b^a	Summer n	Summer r	Summer a^a	Summer b^a
Night								
ΔT_1	207	0.61	2.6	1.5	213	0.31	1.4	0.4
ΔT_2	207	0.63	2.9	0.4	213	0.15	1.1	<0.05
Morning transition								
ΔT_1	104	0.53	3.6	1.5	106	0.17	1.5	0.3
ΔT_2	104	0.67	3.9	0.5	106	0.30	1.8	0.2
Day								
ΔT_1	211	0.26	2.7	0.9	209	0.22	1.3	0.2
ΔT_2	211	0.28	3.5	0.5	209	0.08	1.2	0.1
Evening transition								
ΔT_1	106	0.53	3.7	2.2	106	0.31	1.5	0.4
ΔT_2	106	0.67	4.2	0.8	106	0.25	1.4	0.1
All groups combined								
ΔT_1	628	0.46	2.9	1.2	634	0.24	1.3	0.2
ΔT_2	628	0.57	3.4	0.5	634	0.16	1.2	<0.05

[a] In regression equation $C^* = a + b\,\Delta T$.

Table III—Means and Standard Deviations of Averaged Data

Averaging Period	Winter ΔT_1	Winter ΔT_2	Winter C^*	Summer ΔT_1	Summer ΔT_2	Summer C^*
Night (8-hour)						
Mean	−0.27	−1.62	2.26	−0.76	−1.08	1.13
Std. dev.	±0.44	±1.65	±1.06	±0.26	±2.02	±0.34
Morning transition (4-hour)						
Mean	−0.52	−2.00	2.83	−1.18	−3.21	1.21
Std. dev.	±0.34	±1.45	±1.00	±0.31	±0.57	±0.47
Day (8-hour)						
Mean	−0.74	−2.88	2.05	−1.40	−3.86	1.02
Std. dev.	±0.21	±0.36	±0.70	±0.33	±0.46	±0.33
Evening transition (4-hour)						
Mean	−0.38	−1.91	2.81	−0.95	−2.53	1.13
Std. dev.	±0.29	±1.11	±1.32	±0.24	±0.63	±0.34
Daily (24-hour)						
Mean	−0.47	−2.14	2.37	−1.09	−2.58	1.10
Std. dev.	±0.22	±0.80	±0.67	±0.24	±0.72	±0.31

ception of the morning transition period in which the converse is true.

2. The lowest correlation coefficients occurred in the day period, on a diurnal basis, and in the summer, on a seasonal basis.
3. The correlation coefficients obtained from the ΔT_1-C* analyses were generally higher than those obtained from the ΔT_2-C* analyses in the summer, and the converse was true in the winter.
4. The regression constants were found to be higher in the winter than in the summer, on comparing the interseasonal differences by diurnal period. The lowest regression constants among the diurnal periods in each season occurred in the day period.

Discussion of Results

The factors which would be expected to affect the correlation coefficients are variations in the sampling data caused by other meteorological factors, and sampling errors in the C* and ΔT data. Some of the factors which are expected to change the slope and isothermal intercept constants of the regression line are as follows: (*a*) variations in effective azimuthal source strengths (magnitude and location of sources affecting the sampler); (*b*) variations in the distribution of sources with height; (*c*) diurnal variations in the relationship of wind speed to stability; (*d*) diurnal and seasonal variations in the relationship of wind direction to stability.

On comparing the relationships between averaged data to those between two-hourly data by diurnal classification, it appears that the variations in the data caused by fluctuations in meteorological factors and by sampling errors in both C* and ΔT have been effectively smoothed by obtaining longer time period averages. However, the morning transition period is an exception to this rule because of the wide variations in pollutant concentrations which can be explained in terms of the rapid changes in the vertical temperature structure. This period is conceivably further complicated by rapid changes in source emissions due to increasing urban activity.

By the results obtained from the data averaged by 24-hour periods, it is indicated that this longer time period averaging of data has also minimized the unpredictable random variations in the two-hourly data. Also, it appears that daily mean low-level vertical temperature difference can be used, especially in the winter, as a predictor of daily air pollution concentrations which represent relatively low-level source contributions, without transforming the variables. However, this relationship, essentially, is only describing the nighttime influence of the ΔT's because the most significant results, on a diurnal basis, were found in the sunset to sunrise periods.

Vertical temperature difference, being indicative of vertical dispersion potential, is related to the dilution χ/Q, where χ is the concentration and Q the effective source strength, and not to the concentration only. No data were available from which effective source strengths could be estimated but a general indication of the relative seasonal change in effective source strength can be seen by the decrease in average C* from winter to summer. This, in part, accounts for the fact that the isothermal intercepts and slopes, *a*'s and *b*'s, respectively, of the regression equations are much smaller during the summer period than during the winter period.

Also, on an interseasonal basis, it was noticed that the correlation coefficients are much lower in the summer. This effect is caused, in part, by the sampling error of the C* data. The ranges of the C* data are smaller in the summer than in the winter, because of the decreased effective source strength in the summer, while the sampling error of C* remains approximately constant for all values. Therefore, the ratio of the sampling error variance to the total variance in C* values is greater in the summer thus making the percentages of variance explainable by ΔT and the correlation coefficients lower.

Another consideration in the interseasonal comparison of the regression constants and correlation coefficients is that the character of the sources, such as distribution of sources about the sampler and effective source height, would be expected to differ. During the winter the sources measurable by C* values would likely be more randomly distributed about the sampling site and the effective source height should be lower than during the summer, because home and industrial heating sources play a prominent role in influencing urban air quality in the winter, while these sources are absent in the summer.

The fact that generally higher correlation coefficients were obtained from the ΔT_2-C* analyses than from the ΔT_1-C* analyses in the winter months, along with the summer reversal of the situation, is puzzling. A satisfactory explanation of this effect has not been obtained at the present time.

The data within each of the night and day periods are expected to be the most homogeneous with respect to source and diurnal meteorological variations. Therefore, the highest time-of-day period correlation coefficients would be expected from averaged data for either of these periods. This hypothesis is proved for the night period but not for the day period. However, from a previous pilot study made by the author it is logical to conclude that these results should have been expected in Louisville. This pilot study was a multiple regression analysis of the effects of ΔT_2, wind speed, wind direction, and temperature on C* for night and day periods. It showed that ΔT_2 accounted for the majority of the explained variance during the night period but during the day period wind direction accounted for almost all of the explained variance. From the results of the pilot study and the corroboration of this analysis it can be concluded that during the day period the correlation between C* and either ΔT is almost nonexistent because of the relatively small range of ΔT values. However, this is not true for the night period, in which the range of ΔT values is large enough to subordinate other influences on the pollution concentrations.

The morning and evening transition periods, on the other hand, are not homogeneous periods. In the case of the morning period the changes in the ΔT's and C* are of such a large magnitude that averaging the data obscures the relationships. The physical processes occurring in the morning transition period, such as fumigation beneath a stable atmospheric layer, and also the increases in emissions, contribute to making this period heterogeneous. In the evening period, changes are also occurring, but are not as marked as in the morning period, and therefore the use of averaged data improves the relationships.

Because of the numerous quantitatively unknown physical factors entering into the regression constants obtained, some of which were enumerated at the beginning of this section, no precise description of the actual cause and effect relationships can be made from these data. However, it is suggested by the differences in the slopes by diurnal periods that a straight line fit of the relationship between C* and the ΔT's is not a perfect description of the actual cause and effect relation because of the different ranges of the ΔT's in each these periods. A more precise description would be expected to allow the lines of best fit to curve at the extremes of the ΔT's so that, at both ends of the lines, their slopes would approach zero.

Conclusions

A reasonable fit to a linear relationship can be obtained with no transformation of the variables when ΔT is used to provide an engineering estimate of air pollution concentration. A better linear fit is expected when the concentrations are representative of low-level sources. Therefore, time smoothing of the data, to minimize random local influences and sampling errors, can be accomplished by obtaining simple arithmetic means of homogeneous periods. Also, it is concluded that an arithmetic space smoothing of a network of stations in an urban area would minimize wind direction effects on the combined sampling data.

Data homogeneity, with respect to character of the sources and variations in other meteorological factors at a constant ΔT, can be maximized by diurnal and seasonal classification of the data if short time period air sampling data are used. Also data averaged over a 24-hour period by season are homogeneous because both the small scale meteorological and pollution cycles have periods of 24 hours, and therefore the changes in the average pollution concentrations are caused mostly by changes in dispersion characteristics of which ΔT is a measure.

It is concluded that low-level urban vertical temperature difference measurements are a useful and easily manageable quantitative predictor of surface air pollution concentrations in an urban area. Because of the favorable results obtained from these analyses, further work is being performed to quantitatively estimate some of the factors which affect the slopes and isothermal intercepts of the relationship between C* and ΔT. The factors being studied are variations in the relationship of C* to ΔT caused by diurnal changes in the interrelationships of meteorological parameters affecting the dispersion of pollutants (i.e., wind speed and ΔT), and variations in effective source strength on seasonal, diurnal, and azimuthal bases.

Acknowledgments

Sincere appreciation is expressed to the Jefferson County, Kentucky, Air Pollution Control District for furnishing the reduced two-hourly C* data and to WHAS, Inc. for the use of the television broadcasting tower as a meteorological instrument installation.

REFERENCES

1. H. W. Baynton, "Multiple Correlations of Particulate Air Pollution with Weather Factors at Detroit and Windsor," *Bull. Amer. Meteo. Soc.*, **37**: 333–337 (September 1956).
2. E. H. Markee, Jr., "Relationships of an Air Quality Measurement to Meteorological Parameters," *Amer. Ind. Hyg. Assoc. J.*, **20**: 50–55 (February 1959).
3. R. E. Munn and M. Katz, "Daily and Seasonal Pollution Cycles in the Detroit-Windsor Area," *Int. J. Air Poll.*, **2**: 51–76 (July 1959).

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Preliminary OBSERVATIONS *on the* RELATIONSHIP *between* EYE IRRITATION *in* SYNTHETIC SYSTEMS *and in the* ATMOSPHERE[*]

N. A. RENZETTI, Air Pollution Foundation, and **E. A. SCHUCK,** Stanford Research Institute

Human test subjects have been used in experiments designed to ascertain the eye irritants generated when certain hydrocarbons are irradiated in the presence of nitrogen dioxide. These same subjects have been used to measure eye irritation intensities in the Los Angeles Basin. Certain variables affecting eye irritation measurements have been studied as a first step in relating irritation in synthetic systems to irritation observed in Los Angeles smog.[†]

Experimental Techniques

A diagram of the facility in which the synthetic systems were examined is shown in Fig. 1.[1] Auto exhaust mixtures or other mixtures containing hydrocarbons and oxides of nitrogen were irradiated with near-ultraviolet light in the 520-cubic-foot reaction chamber. At the end of two hours of irradiation, the subjects were asked to judge the eye irritation intensity of the mixture as it flowed by their eyes. The eye irritation intensities were measured by two methods.

1 By piping the reacted mixture to subjects seated in the booths outside the chamber (see Figs. 1 and 2).

2 By having the subjects stand at openings (eye ports) in the sides of the chamber to judge the irritation intensity. A baffle prevented direct ultraviolet irradiation of the eyes but did not interfere with irradiation of the gas mixture.

In both methods the subjects reported eye irritation at 30-sec intervals as none, light, medium, or severe. Each subject was exposed for a five-minute period. The reports were assigned numbers (0, 1, 2, 3, and so on) and used to calculate an eye irritation index for the panel of 10 subjects. The resulting indices were as follows: 0 to 6, none to light irritation; 6 to 10, light to medium irritation; 10 to 16, medium to severe irritation. At an index of 16 and above, the irritation caused lachrymation in more than 50% of the subjects.

Discussion of Test Data and Hypotheses

In the laboratory experiments the subjects were exposed in the test booths to irradiated mixtures of three ppm of certain hydrocarbons and one ppm of nitrogen dioxide. In Table I are tabulated the results obtained using a few of the many mixtures studied. These results have previously been reported elsewhere.[1, 2]

A study of the observable products formed in these reactions led us to the conclusion that the measured amounts of formaldehyde and acrolein could account for the observed irritations.[2] We then directed our attention to the question: Can these be the irritants responsible for the irritation experienced by the public in Los Angeles smog? We recognized that in doing this we would be seeking answers to a number of perhaps unanswerable questions. However, the results justified the approach.

We first sought data that would enable us to answer the question: Does the panel response accurately measure the actual irritant levels in

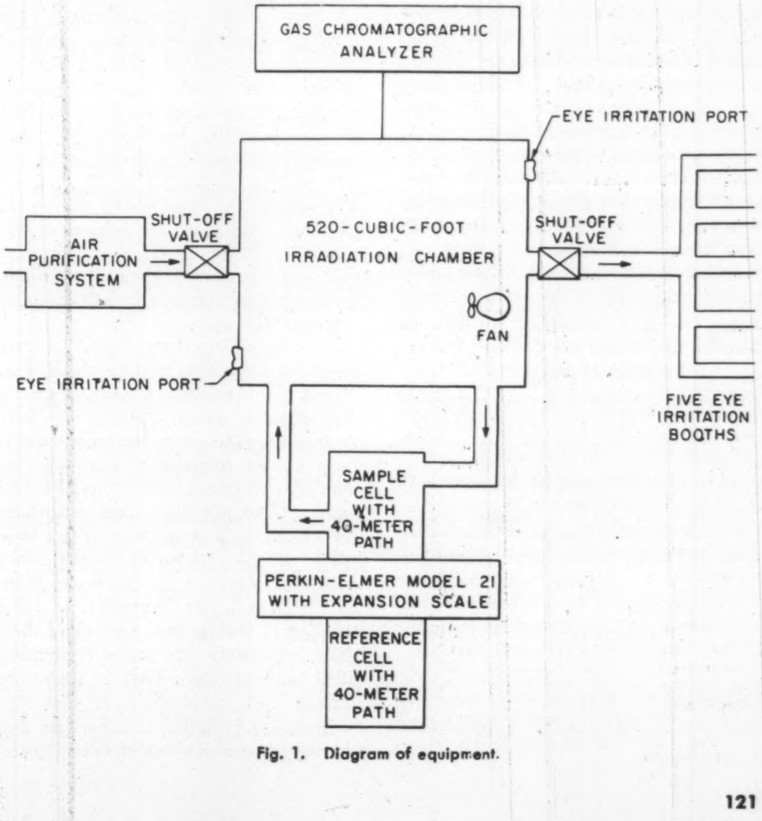
GAS CHROMATOGRAPHIC ANALYZER
EYE IRRITATION PORT
SHUT-OFF VALVE
AIR PURIFICATION SYSTEM
520-CUBIC-FOOT IRRADIATION CHAMBER
SHUT-OFF VALVE
FAN
EYE IRRITATION PORT
FIVE EYE IRRITATION BOOTHS
SAMPLE CELL WITH 40-METER PATH
PERKIN-ELMER MODEL 21 WITH EXPANSION SCALE
REFERENCE CELL WITH 40-METER PATH

Fig. 1. *Diagram of equipment.*

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[*] Presented at the 53rd Annual Meeting of APCA, Netherland-Hilton Hotel, May 22-26, Cincinnati, Ohio.

[†] This investigation was performed at Stanford Research Institute and was supported by a PHS research grant RG 6828 from the Division of General Medical Sciences, Public Health Service, and by the Air Pollution Foundation.

Fig. 2. Eye irritation measurements at booths.

Table I—Eye Irritation Indices at Booths for Irradiated Mixtures of 3 Ppm of Hydrocarbons and 1 Ppm of Nitrogen Dioxide

Hydrocarbon Tested	Eye Irritation Index, Arbitrary Units
1-pentene	14.8
Trans-2-butene	7.6
Butadiene	22.0
1-Butene	5.6
Isopentane	3.2
3-Methylpentane	2.4
Cyclohexene	8.0
Cyclohexane	2.0

the irradiation chamber? The response could be low, either because short-lived irritants were decomposed or otherwise destroyed in the 15 sec that it takes the irritants in the irradiation chamber to travel to the test booths or because the irritants were sufficiently diluted in our method of exposing the subjects' eyeballs to result in significant reduction in the concentration of the irritants. Therefore, we proceeded to determine whether one would obtain more irritation by making observations in the chamber proper.

The results of the observations made at the eye ports in the chamber while the mixtures were being irradiated are presented in Table II. These irritant indices are about twice as large as those obtained in the booths for the same initial reactant concentrations, thereby giving support to the hypothesis that our panel observations might be low. These data suggested that we run some experiments with a known irritant with observations to be made both at the booth and at the ports. Formaldehyde was used, and the results of tests with this irritant are shown in Table III. We concluded that (*1*) irritation is indeed greater at the eye ports than at the booths, since the measured formaldehyde concentration was essentially the same at the two test points and the 12°C difference in temperature apparently was not responsible for the difference; and (*2*) the possibility that certain irritants are shortlived need not be postulated, since a difference in the two indices also resulted with a stable irritant in both dark and irradiated conditions.

Table II—Eye Irritation Indices at Booths and Ports for Certain Photo-oxidized Mixtures

Olefin Tested[a]	Concentration of Nitrogen Dioxide, Ppm	Eye Irritation Index Arbitrary Units At Booth	At Port
Propylene	0.3	6.0	16.0
Propylene	0.9	6.4	11.6
Propylene	3.0	5.6	12.4
2-Methyl-2-butene	3.0	10.8	21.8
Isobutylene	0.1	6.3	13.2
Isobutylene	0.3	12.8	16.7
Isobutylene	0.9	10.4	21.4
Isobutylene	3.0	8.8	16.8

[a] At 3 ppm.

Another question now arises: Why is the index greater at the port than at the booth? We do not know nor do we believe that the answer, when found, will have an important bearing on the subject of this paper. The extensive series of experiments conducted has established that we have a sensitive and reproducible method of measuring eye irritation at the chamber ports. We must admit to some bias in this matter, however, since the readings turned out to be higher at the port than in the booths, which supports the validity of questioning the panel response. We place the subject of this difference in the hands of our eminent colleagues in the fields of physiology and psychology of eye irritation measurement techniques.

As a parallel to these experiments we used the same human test subjects to obtain eye irritation measurements in Los Angeles smog. Here, we were trying to determine the relationship between the response of our panel to synthetic mixtures and to atmospheric smog. The subjects were asked to report, in a manner similar to that used in the chamber experiments irritation observed in the atmosphere at 2 PM each day, regardless of their location in the Basin. A graph of their daily response for the period September 1959, through April 1960, is shown in Fig. 3.

It should be noted that on one day during this period (October 16) irritation was quite severe. A check of the individual records for that day shows that observations were made in Los Angeles, Hollywood, Alhambra, and Pasadena. Of the 12 subjects, nine reported severe irritation, two reported medium irritation, and one reported light irritation.

We believe that these data on irritation observed in the atmosphere are important to our hypothesis in the following ways.

A To our knowledge these are the only data resulting from the use of the same test subjects to monitor eye irritation in both laboratory systems and atmospheric smog. We have, therefore, been able to obtain some qualitative relationship between these sets of data.

B The relationship between the response of our panel to atmospheric smog and the response representative of the public-at-large appears to be reasonable when one looks at the comparison presented in Table IV. For this table we chose the month of October, which was characterized by considerable eye irritation throughout the Basin, and tabulated the responses of the Los Angeles County Air Pollution Control District panel and our panel for the same days. We believe that the differences in the test data may be explained by differences in the locations and the times of observation of the two panels.

Table III—Eye Irritation Indices for 3 Ppm of Formaldehyde

Test Number[a]	Temperature of Air Reaching Subjects' Eyes, °C At Booth	At Port	Eye Irritation Index, Arbitrary Units At Booth	At Port
1	25	37	12.8	21.8
2	25	37	11.0	20.0
3	—	37	—	18.2
4	—	25	—	20.0

[a] Tests 1, 2, and 3 were conducted with irradiation.

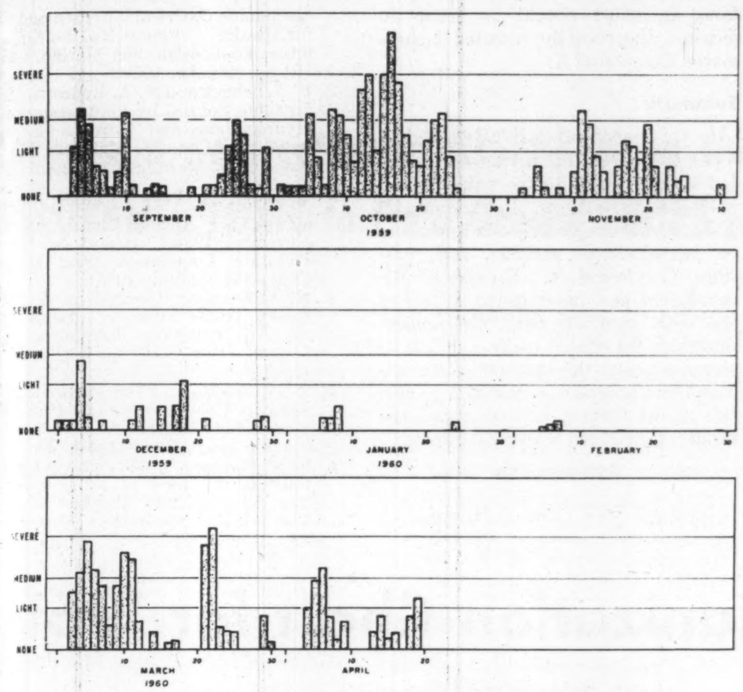


Fig. 3. Eye irritation observed in East Los Angeles Basin at 2 PM.

To make a more specific test of the response of our panel to synthetic smog and atmospheric smog, we proceeded on the few smog days available to us for these experiments, as follows.

The panel was asked to report on eye irritation observed immediately outside the laboratory. In those cases where they reported irritation, the following procedure was adopted. The test chamber was filled with outside air, and the subjects made observations on this mixture in the regular manner in the test booth. These experiments resulted in the data shown in Table V. It appears from these data that the index for outside air was approximately twice that for the same air passed to the subjects from the chamber to the booths.

Table IV—Eye Irritation—Los Angeles Smog

Month	Date	Eye Irritation from Fig. 3	Eye Irritation Level at Los Angeles Civic Center[a]
October	5	13	Heavy
"	8	12	"
"	16	22	"
"	22	10	"
"	23	11	"
"	13	16	Medium
"	9	10	Light
"	12	14	"
"	15	15	"

[a] APCD Report on Meteorology Air Pollution Effects and Contaminant Maxima for October 1959. Project 050513.

The final question in this series is: With the test chamber filled with outside air, will the response measured at the ports be the same as measured directly in the atmosphere? We have not obtained data providing an answer to this question.

We have thus far been concerned with questions related to the response of our panel to the various laboratory and atmospheric situations. This examination has given us some confidence that if we could now relate the concentrations of either the reactants or the products in the chamber to the concentrations in the atmosphere we would be well along in our effort to demonstrate that formaldehyde and acrolein are the primary irritants in Los Angeles smog.

First, let us direct our attention to the probable concentrations of the reactants in the atmosphere. Most of the data on hydrocarbon concentration have been reported as parts per million of hexane.[3, 4] Furthermore, the infrared techniques used have been insensitive to the olefins probably present and particularly insensitive to ethylene. We believe that auto exhaust emissions constitute the primary source of olefins in smog. A considerable amount of data are available on olefin concentrations in exhaust, and it is our contention that by putting all of these data together we can estimate the olefin concentrations in atmospheric smog to be of the order of one ppm for ethylene and 0.25 to 0.75 ppm for the remaining olefins. In considering nitrogen oxides, we are in a somewhat better position. The extensive data that have been obtained on these pollutants over a period of several years suggest that the atmospheric concentrations range from 0.5 to one ppm. If one compares these hydrocarbon and nitrogen oxide concentrations with those in our chamber experiments, we submit that, within a factor of perhaps two or three, one can say that comparable eye irritation levels are obtained by irradiation of these reactants in the chamber and in the atmosphere.

Table V—Eye Irritation Indices for Outside Air

Date	Measured in Atmosphere	Measured in Booths
10/7	0.7	1.3
10/9	4.0	6.0
10/12	14.0	8.0
12/4	16.0	8.0

The situation in regard to formaldehyde and acrolein, however, is not quite as clear. It appears that in our chamber experiments, even at the ports, one needs about one ppm of formaldehyde to obtain light-to-medium eye irritation. Unfortunately, there have been very few measurements of formaldehyde and acrolein in the atmosphere. The only rather meager data that are available are on total aldehydes, as measured by the bisulfite analytical procedure, and these data have indicated concentrations of about 0.3 to 0.7 ppm of total aldehydes. When considering that there are other aldehydes, notably acetaldehyde and higher aldehydes, one must estimate that the concentrations of formaldehyde and acrolein in the atmosphere are probably less than 0.4 ppm.

We must conclude from all of this that the validity of our case is indeterminate. However, there appears to be sufficient evidence to indicate that our original hypothesis can lead to the explanation of eye irritation in Los Angeles smog and warrants making a specific examination of the aldehyde concentrations in the atmosphere concurrently with eye irritation observations. Furthermore, a completely independent set of experiments might support our position. Melekhina[5] determined that 0.07 ppm of formaldehyde is a threshold value for eye reflex action and recommended that 0.03 ppm be the maximum permissible limit for formaldehyde in the atmosphere.

Finally, recent results obtained by Stephens, et al.,[6] have indicated that the smog reaction leads to another lachrymator, Compound X, compatible in irritant potential to formaldehyde. In our laboratory experiments we found the concentration of Compound X to be small compared to that of formaldehyde. However, this situation may not exist in smoggy atmospheres.

Recommendations

We believe the model presented here to be sufficiently realistic to indicate that an intensive program of atmospheric sampling should be undertaken with effort focused on relating eye irritation observations and aldehyde concentrations. The primary objective in measuring aldehydes should be to obtain accurate data on formaldehyde and acrolein concentrations. In addition, an effort should be made to measure the recently reported lachrymator, Compound X.

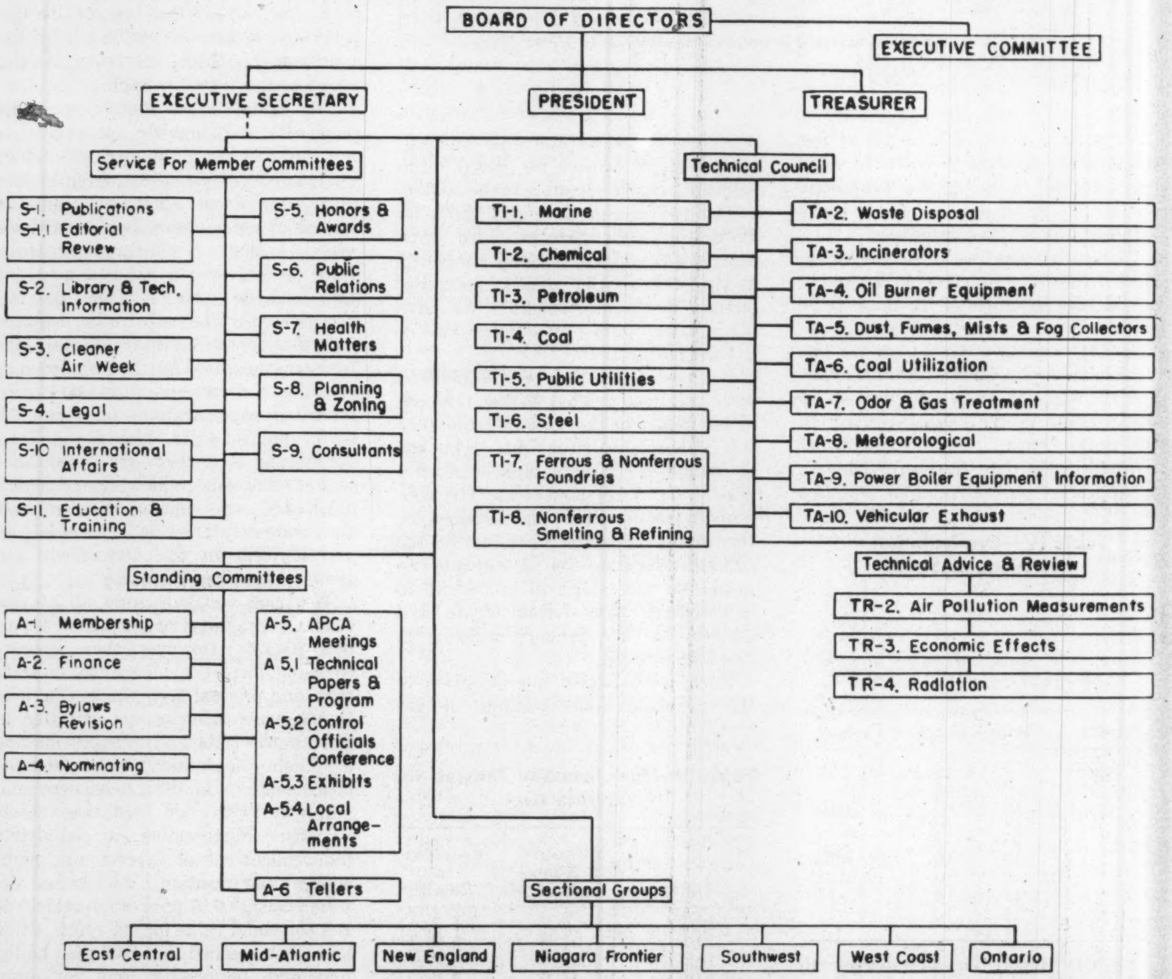
Summary

In this paper we have attempted to relate the eye irritation values found in Los Angeles smog to the values found in laboratory mixtures. In the synthetic systems, the major irritants appear to be formaldehyde, acrolein, and, possibly, Compound X. Because of the insufficient and inconclusive nature of the data obtained from atmospheric sampling, we cannot make a definitive statement on this matter. An atmospheric program is essential to test this model further, and we await the results of this study with great interest.

REFERENCES

1. E. A. Schuck and G. J. Doyle, "Photooxidation of Hydrocarbons in Mixtures Containing Oxides of Nitrogen and Sulfur Dioxide." Report No. 29, Air Pollution Foundation, San Marino, Calif., 104 pp. (October 1959).
2. E. A. Schuck and N. A. Renzetti, "Eye Irritants Formed by Photooxidation of Hydrocarbons and Nitrogen Oxides." Presented at the Air Pollution Control Association Meeting, Cincinnati (May 23, 1960).
3. N. A. Renzetti, "An Aerometric Survey of the Los Angeles Basin, August–November 1954." Report No. 9, Air Pollution Foundation, San Marino, Calif., 334 pp. (July 1955).
4. N. A. Renzetti, "Analysis of Air Near Heavy Traffic Arteries." Report No. 16, Air Pollution Foundation, San Marino, Calif., 28 pp. (December 1956).
5. V. P. Melekhina, "The Maximum Permissible Concentration of Formaldehyde in the Atmospheric Air." *Gigiena i. Sanit.* **23**: 8, 10–14 (1958).
6. E. R. Stephens, et al., "Photochemical Reaction Products in Air Pollution." Div. Refining, 25th Midyear Meeting, Am. Petrol. Inst., Detroit (May 1960).

APCA's Organization Chart for 1961



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ORGANIZATION CHART—The above chart will appear in the 1961 Membership Directory. It includes the latest changes in the APCA committees.

Status and Redirection of RESEARCH *on the* ATMOSPHERIC POLLUTANTS TOXIC *to Field Grown* CROPS *in Southern California**

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Atmospheric pollutants in the Los Angeles area toxic to vegetation are becoming more clearly defined and their vegetational suscepts determined. Two specific compounds, both with high oxidizing and phytotoxic potentials, are now known. Further it is becoming obvious that these known oxidants are essentially reaction products of atomic oxygen formed by the photolysis of nitrogen dioxide with a wide range of gaseous hydrocarbon.[1–4] Again research studies show that these oxides of nitrogen and the wide spectrum of hydrocarbons are incident to the energy requirement of our modern highly industrialized and mobile society. The over-all composition of urban atmospheres is never constant; varying in time with topography, intensity of insolation, with various meteorological phenomena, and with the type and concentration of transportation facilities.[5, 6]

Concerned with the phytotoxicants in the atmosphere of the upper Santa Ana Basin of Southern California, this paper has two principal objectives: first, to indicate the specific pollutants at present known to be phytotoxic and second, to describe the Agricultural Air-Research Program (AARP), a program designed to evaluate in the field the impact and economic significance of these phytotoxicants.

Early Concept of Atmospheric Pollutants Injurious to Vegetation in the Los Angeles Area

What is reported as typical Los Angeles "smog injury" to vegetable crops was observed first in 1944.[7] Subsequent research including histological studies[2, 8, 9] have provided accurate characterizations of this injury and have extended the suscept range of vegetation affected. In general, primary symptoms so described involve the lower epidermis and the spongy mesophyll tissue of the leaves. Injury is externally recognized first in the form of water soaked tissue, later developing into silvering, glazing, bronzing, or blistering of the lower epidermis and contiguous mesophyll cells. Damage to the leaf mesophyll, however, may be so severe that entire collapse of leaf tissue results.

As early as 1952, symptoms on vegetable crops referred to as "Los Angeles smog-type injury" were reproduced experimentally with reaction products of ozonized hydrocarbons.[2] It was also determined that the ozone and other phytotoxic oxidants responsible for such injury were produced by the action of photolyzed NO_2 on unsaturated hydrocarbons.[2] Various workers have subsequently duplicated these early experiments and have greatly expanded the number of leafy vegetable crops on which such symptoms are expressed.[10] While somewhat different symptomatological patterns have been noted to appear on such plants as alfalfa and various cereals, it appears that all have been accepted in the past as suscepts of what has been regarded as the recently discovered class of phytotoxic oxidants.[2, 7, 10, 11] The recognized "smog-type" symptoms resulting from the impact of these oxidants were considered essentially as an undifferentiated group complex. As late as 1957, it was recognized that no one plant-damaging oxidant with its resultant symptomatological syndrome had been specifically identified.

Essentially all early estimates of economic losses attributed to air pollutants in the Southern California areas have been based on injury observed on these leafy vegetables and on a limited number of other herbaceous crops.[11]

Ozone as a Known Oxidizing Pollutant Toxic to Vegetation

Abnormally high ozone concentrations have been reported from various geographical areas.[12–14] It has been observed also that under experimental conditions ozone at relatively low concentrations is highly phytotoxic.[11] Furthermore, early research established the fact that ozone is generated by the same photochemical reactions of organic materials and oxides of nitrogen as the "oxidants" reported to cause the general "smog" or "oxidant" plant damage.[3, 4, 6, 14]

While ozone is recognized as an extremely active phytotoxicant under experimental conditions, and is found in abnormally high concentrations in many areas, its impact and significance as a toxicant on field grown crops have remained unknown. As late as 1956, it was recorded that there is no evidence that ozone is responsible for much crop damage.[15] Later in 1958, it was stated that when all the typical symptoms of smog have been reproduced the problem remains of accounting for the relatively high ozone content in the polluted atmosphere.[5]

Ozone Injury to Grape

Ozone was first definitely recognized as a significant atmospheric phytotoxicant in the co-operative studies on grape stipple by personnel of Kaiser Steel Corporation and the University of California Citrus Experiment Station, 1954 to 1958. The disorder was observed in the field as early as 1954. During 1955 the symptomatological syndrome of what was then reported as a specific but new disease of the grape was critically worked out and the name "stipple" applied.[16] Studies during 1956 confirmed those of 1955, and stipple-like lesions were produced on a number of grape varieties in preliminary fumigations with ozone. During 1957 extensive fumigations with ozone on 16 varieties of grapes established the visual identity of stipple lesions produced experimentally by ozone with those observed on the same varieties in the open vineyards.[16–18] In contrast with the traditional "oxidant injury" on leafy vegetation, the characteristic ozone lesions in the grape appear on the upper leaf surface and

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Table I—Type and Degree of Injury Caused by Oxidants on Leaves of Petunia and Pinto Bean Plants in Various Stages of Maturity[a]

Injury Caused by	Type and Degree of Injury on Plant Leaves						
	Petunia			Pinto Bean			
	Bronzing and Silvering of Immature Leaves	Banding of Expanding Leaves	Tissue Collapse of Mature Leaves	Bronzing and Glazing		Tissue Collapse	
				7-day-old Leaves	14-day-old Leaves	7-day-old Leaves	14-day-old Leaves
Ambient air	xxx	xxx	0	xxx	xx	x	xxx
Ozone above 0.3 ppm	0	0	xxx	0	x	x	xxx
Ozone-hexene	0	0	0	0	xxx	0	x
Irradiated (NO_2 + 1-hexene)	xxx	xxx	0	xxx	0	0	0

[a] Degree of leaf injury: 0 = none; x = light; xx = moderate; xxx = severe.

in the form of small light brown to black discrete punctate lesions varying in diameter from 0.1 to 0.5 millimeter. Once formed, such lesions seldom increase in size, although with continued seasonal accumulation, lesions may coalesce affecting larger tissue segments. Probably the most characteristic feature of the primary stipple lesions in the grape is the degree to which the damaged tissue areas are restricted in their distribution to the chlorophyll-laden palisade parenchyma of the leaf. Such damaged areas are readily observed through the apparently undamaged epidermis and cuticle.

While ozone stipple occurs on grapes in apparently damaging proportions throughout the smog affected areas in Southern California, no attempts have been made to critically assess the economic damage of ozone to the grape crop. However, with the accumulation of upper surface lesions, leaf senescence is advanced, usually resulting in premature leaf drop and fruit exposure.

Ozone Injury to Citrus and Other Woody Plants

Field observations and fumigation studies at the University of California Citrus Experiment Station in Riverside indicate that avocado and various citrus species are affected adversely by ozone. Stipple-like lesions were observed by the authors on citrus as early as 1955. Comparable lesions were produced by fumigation with ozone during 1956–57.[19] Lesions so produced were, in general, stipple-like, varying in size and in color and were restricted in their distribution primarily to the palisade parenchyma of the leaf. Leaf drop and reduced growth rate resulted where young potted citrus trees were fumigated with synthetic ozone.[19]

In addition to grapes, avocado, and citrus, ozone stipple-like lesions have been observed on a wide range of species and varieties of woody plants, including a number of broad-leaved trees and shrubs. Field observations and limited experimental evidence obtained at the Citrus Experiment Station suggest the probability that pine needle mottle, or what is referred to as the "X disease," is ozone induced.

Ozone Injury to Tobacco

The report of ozone stipple on grape in early 1958[17] provided the clue to the possibility that weather fleck of tobacco, the etiology of which was unknown,[20] might be caused by ozone. It is now generally accepted that this disease, reported to cause losses of from two to 10 million dollars annually and extending in its distribution from the Carolinas to Ontario, Canada, is an ozone-induced phenomenon.[12, 13, 21] As in ozone stipple of grape, ozone fleck of tobacco affects local areas in the upper surface of the leaf. Histological studies show the same characteristic restriction of injured cellular tissue to the palisade parenchyma as found in the grape.[17, 20, 21] Abnormally high concentrations of ozone are reported to be correlated with the occurrence of fleck in various tobacco growing areas.[13]

Ozone Injury to Vegetable and Various Herbaceous Crops

Earlier studies[15, 20] and information recently made available[19, 21, 22, 23] clearly indicate that in the field and under experimental conditions in the greenhouse, ozone injury to vegetable and various herbaceous plants may take on a wide variety of expressions, dependent upon the type and maturity of the suscept, the concentration of the ozone and the length of exposure time. Injury to older or fully expanded leaves varies from small fleck or stipple-like lesions to generalized chlorosis or bleaching of the upper leaf surface. High concentration of ozone may result in partial or total collapse of the entire leaf mesophyll.[15] On a wide range of vegetation, shothole and pitting may result with tissue breakdown in older fleck or stipple lesions.[19, 21, 23]

Ozone-type upper surface bleaching has been observed by the authors on leafy vegetables in the Los Angeles area, concurrent with the typical silvering, bronzing, and more severe symptoms assumed to be induced by other atmospheric toxicants.[19, 23] Recently ozone-type injury has been reported as a critical factor in vegetable production in New Jersey.[24] It may be shown ultimately that ozone is one of the most critical phytotoxic pollutants.

Peroxyacetyl Nitrite (PAN) as an Air Pollutant Toxic to Vegetation

Stephens, et al.,[25] have recently provided the first experimental breakthrough into the real nature and possible chemical composition of the phytotoxic "oxidants." What has been referred to as peroxyacetyl nitrite (PAN), Stephens has isolated in pure form, determined its probable chemical structure, and has established its existence as an atmospheric pollutant. Stephens has shown further that PAN, like ozone, is a reaction product of photolyzed nitrogen oxides on unsaturated hydrocarbons.

Used as fumigants both PAN[25] and a photolyzed mixture of nitrogen dioxide and hydrocarbons[26] were found to induce smog or "oxidant-like symptoms" on a number of herbaceous plants. The nature of symptoms produced, consisted of silvering, bleaching, and bronzing of the lower leaf epidermis and contiguous tissues.[25, 26] The most unusual effect noted was the consistency with which the toxicity of PAN is restricted to a definite stage of tissue maturity thereby resulting in a specific localization of the injured tissues.

Table I illustrates the comparative symptomatology produced when plants are exposed under comparable conditions to polluted ambient air, to ozone, to ozone-olefin reaction compounds and to PAN. It will be noted that ozone and ozone-olefin products are restricted in their toxic effect essentially to fully expanded leaf tissue—whereas, PAN appears to affect or to be most toxic to younger expanding tissue. It will be noted also that lower leaf surface silvering and bronzing is a characteristic feature of the injury produced by PAN.

Fluoride, a Phytotoxicant in the Upper Santa Ana Basin Area

Fluorides do not comprise an integral part of the composition of the Los Angeles type smog.[27] When present in abnormally high concentrations, emissions can be traced usually to certain local industrial operations. Survey by various Citrus Experiment Station personnel using visible symptoms on sensitive plants, coupled with leaf analysis, have established the presence of abnormal concentration of fluorides in certain areas of the upper Santa Ana Basin.[28, 29] The extent to which such levels are damaging to vegetation is not known. However, the literature is replete with reports as to the effect of fluorides on various forms of vegetation.

In general fluorides taken up by leaves of sensitive plants appear to move outward to the leaf periphery where they may reach toxic or lethal levels killing tissues at the leaf margin. Whether sublethal or subnecrotic concentrations cause economic damage to sensitive plants under natural field conditions remains to be determined.

Phytotoxicants Present in the Upper Santa Ana Basin

Available information permits the singling out of at least three specific phytotoxicants or groups of phytotoxicants known to be present in the atmosphere of the upper Santa Ana Drainage Basin: ozone, peroxyacetyl nitrite (PAN), and fluorides. However, we cannot rule out the probability that one or possibly many phytotoxic components derived from ozonated hydrocarbons or from various photolytic induced reactions of nitrogen oxides and other atmospheric components may remain unidentified.

Need for Specific Redirection of Research and for Broadening Public Support

Greenhouse experiments with citrus at the University of California Citrus Experiment Station show that when the ambient air supply is passed through activated carbon filters growth and water use are increased and that leaf drop is generally decreased. Artificially controlled laboratory and greenhouse experiments at various research institutions have shown also that certain atmospheric phytotoxicants can affect fundamental physiological processes within plants. However, owing to the artificial conditions under which such results have been obtained, none of the various experiments has been devised so as to provide reliable indices as to the effect of the various phytotoxicants on crops under field conditions.

It became evident therefore that in the Southern California area field studies must be undertaken to determine the effect of the various phytotoxicants on yields, growth and quality of fruits and other crop products. Such field studies, especially on tree fruits, were recognized to be costly and to demand the highest type of research competence. Recognition of the basic significance of the field approach and of the magnitude and cost of the problems involved has brought into existence a co-operative research program organized and functioning under the official designation of the Agricultural Air-Research Program—the AARP of Southern California, located at and administered by the University of California, Riverside.

The program is a unique co-operative effort supported by agriculture, industry, local government, various private organizations, and the University of California.[30] It is an over-all organized effort to assemble, co-ordinate, and focus the needed scientific and technical training and experiences on the growing air pollution problems as they relate to agriculture.

Objectives of Agricultural Air-Research Program

The scope and general objectives of the Agricultural Air-Research Program are, to quote from the original plan:[31] "to measure under field conditions the effect of the various atmospheric phytotoxicants on agriculture crops growing in the upper Santa Ana Drainage Basin. As previously stated, such measurements include plant growth, crop yield, longevity and the quality and keeping property of fruits and other agricultural products." The concept of atmospheric phytotoxicants to be included in the research as already discussed are: ozone, peroxyacetyl nitrite (PAN), and fluorides.

Procedure Involved in the Agricultural Air-Research Program

It is proposed that initially a total of 48 lemon trees will be used, 24 in each of two comparable producing groves. In each grove, 20 trees comprising five separate groups of four trees each will be individually enclosed in cabinets so constructed and operated as to deviate as little as necessary from the cultural conditions under which the trees are normally growing. The groups of four trees individually enclosed will be grown in air modified in each of the following ways:

Group	Modification of Air
1	In air filtered to remove atmospheric phytotoxicants.
2	In ambient air with no modification in concentration of phytotoxicants.
3	In air treated to remove fluorides without modifying the oxidant content.
4	In air treated to remove oxidants without modifying the fluoride content.
5	In air filtered as in #1 but with fluorine added in the form of HF to the amount that the fluorine added will equal the concentration of the "gaseous" portion of the total fluorides in the ambient air.
6	Four trees grown without enclosures.

Research Problems Underlying the Implementation of Studies

From the outset, the Technical Committee[31] in formulating the Agricultural Air-Research Program recognized that many unsolved technical and engineering problems would be involved.

While we can filter out the various toxicants from the ambient air as required in No. 1, no system or systems have as yet been devised for complete separation of the various phytotoxicants in ambient air; fluorides from oxidants and oxidants from fluorides as required in Groups 3 and 4 respectively. Refinement of air sampling and recording techniques remain as problems for refinement both for oxidants and fluorides, as do the measurements and automatic recording of the gaseous portion of the total atmospheric fluorides and oxidants.

The design of tree enclosures which will facilitate treatment and reliable measurement and, yet possessing a flexibility essential for the study of a variety of crop types, imposes critical technological difficulties.

The planned objectives of the Agricultural Air-Research Program are entirely consistent with the valued concepts and procedures of fundamental or basic research. Results obtained under the program may add significantly to our present scientific knowledge, likewise to the technological processes and instrumentation essential to advance atmospheric research. Recent refinement of instrumentation keyed to measure and automatically record gaseous fluorides at concentrations of 0.1 ppb serves as a case in point. Other problems equally significant and challenging confront the highly trained and experienced personnel of the new research organization. To achieve the objectives of the Agricultural Air-Research Program, these problems must be met and solved.

REFERENCES

1. A. J. Haagen-Smit, "Chemistry and Physiology of Los Angeles Smog." *Ind. and Eng. Chem.*, **44**: 1342–1346 (1952).
2. A. J. Haagen-Smit, E. F. Darley, M. Zaitlin, H. Hull, and W. Noble, "Investigation on Injury to Plants from Air Pollution in the Los Angeles Area." *Plant Phys.*, **27**: 18–34 (1952).
3. E. R. Stephens, P. L. Hanst, R. C. Doerr, and W. E. Scott, "Reactions of Nitrogen Dioxide and Organic Compounds in Air." *Ind. and Eng. Chem.*, **48**: 1498–1504 (1956).
4. E. R. Stephens, W. E. Scott, P. L. Hanst, and R. C. Doerr, "Recent Developments in the Study of the Organic Chemistry of the Atmosphere." Proc. API 36(III): 288–289 (1956). Reprinted in *J. Air Poll. Control Assn.*, **6**: 199 (November 1956).
5. A. J. Haagen-Smit, "Air Conservation." *Science*, **128** (3329): 869–878 (1958).
6. E. R. Stephens, P. L. Hanst, R. C. Doerr, and W. E. Scott, "Auto Exhaust: Composition and Photolysis

Products." *APA Jour.*, **8**: 4: 333–335 (1959).

7. J. T. Middleton, J. B. Kendrick, Jr., H. W. Schwalm, "Smog in the South Coastal Area." *Calif. Agri.*, **4**: 11: 7–10 (1950).
8. Ruth A. Bobrov, "The Effect of Smog on the Anatomy of Oat Leaves." *Phytopath.*, **42**: 558–563 (1952).
9. Ruth A. Bobrov, "The Anatomical Effects of Air Pollution on Plants." Proc. Sec. Nat. Air Pollution Symp., 129–163 (1952).
10. J. T. Middleton, J. B. Kendrick, Jr., and E. F. Darley, "Air Pollution Injury to Crops." *Calif. Agri.*, **7**: 11: 11, 12 (1953).
11. J. T. Middleton, E. F. Darley, and R. F. Brewer, "Damage to Vegetation from Polluted Atmospheres." *J. Air Poll. Control Assoc.*, **8**: 1: 9–15 (May 1958).
12. H. E. Heggestad and J. T. Middleton, "Ozone in High Concentrations Cause of Tobacco Leaf Injury." *Science*, **129**: 208 (1959).
13. R. C. Wanta and Howard E. Heggestad, "Occurrence of High Ozone Concentrations in the Air near Metropolitan Washington." *Science*, **130**: 103–104 (1959).
14. A. J. Haagen-Smit and Margaret M. Fox, "Automobile Exhaust and Ozone Formation." Presented at the SAE Golden Anniversary Annual Meeting, Detroit (Jan. 1955).
15. J. T. Middleton, A. S. Crafts, R. F. Brewer, and O. C. Taylor, "Plant Damage by Air Pollution." *Calif. Agri.*, **10**: 6: 9–12 (1956).
16. B. L. Richards, "A Stipple Disease of the Grape—a Problem in Air Pollution." Unpublished report (1957).
17. B. L. Richards, J. T. Middleton, and W. B. Hewitt, "Air Pollution with Relation to Agronomic Crops: V. Oxidant Stipple of Grape." *Agron. Jour.* **50**: 559–561 (1958).
18. B. L. Richards, J. T. Middleton, and W. B. Hewitt, "Ozone Stipple of Grape Leaf." *Calif. Agri.*, **13**: 12, 4 and 11.
19. O. C. Taylor, Unpublished Data—on file in the Dept. of Horticulture.
20. L. W. Burk and H. E. Heggestad, "Weather Fleck of Nicotiana Tobacum." *Plant Disease Reporter*, **40**: 5: 424–427 (1956).
21. Anonymous, "Ozone Causes Tobacco Fleck." *Agri. Res. Serv.*, USDA **7**: 9: 8 and 9 (1959).
22. Myron C. Ledbetter, P. W. Zimmerman, and A. E. Hitchcock, "The Histopathological Effects of Ozone on Plant Foliage." *Contrib. Boyce Thompson Inst.*, **20**: 4: 275–282 (Oct. to Dec. 1959).
23. B. L. Richards, "Observations on Ozone Injury to Vegetation 1954 to 1959." Unpublished.
24. Robert H. Daines, Ida A. Leone, and Eileen Brennan, "Air Pollution as It Affects Agriculture." *New Jersey Bull.*, **794**: 3–14 (1960).
25. E. R. Stephens, E. F. Darley, O. C. Taylor, and W. E. Scott, "Photochemical Reaction Products in Air Pollution." Presented at the 25th mid-year meeting (Refining), *Amer. Pet. Inst.* at Detroit, Mich. (May 1960).
26. O. C. Taylor, E. R. Stephens, E. F. Darley, and E. A. Cardiff, "Injury to Pinto Bean and Petunia Foliage by Air-Borne Oxidants." To be published in *Amer. Soc. for Hort. Sci.*, **75**: (1960).
27. M. D. Thomas, "New Understandings from Current Atmospheric Pollution Research." *Amer. Jour. of Public Health*, **49**: 12: 1664–1669 (1959).
28. J. C. Kaudy, F. T. Bingham, R. C. McColloch, G. F. Liebig, and A. P. Vanselow, "Contamination of Citrus Foliage by Fluorine from Air Pollution in Major California Citrus Areas." *Proc. Amer. Soc. Hort. Sci.*, **65**: 121–127 (1955).
29. R. F. Brewer, R. C. McColloch, and F. H. Sutherland, "Fluoride Accumulation in Foliage and Fruit of Wine Grapes Growing in the Vicinity of Heavy Industry." *Amer. Soc. Hort. Sci.*, **70**: 183–188 (1957).
30. Anonymous, "New Smog Study Planned." *Calif. Citrog.*, **44**: 10: 322 (Aug. 1959).
31. B. L. Richards, Unpublished report of the Technical Committee to the Chairman of the Policy Committee of the Agricultural Air-Research.

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The OCCURRENCE, DISTRIBUTION, *and* SIGNIFICANCE *of* PHOTOCHEMICAL AIR POLLUTION *in the* United States, Canada, and Mexico*

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Air pollution results when contaminants from man's activities are emitted to the atmosphere and fail to disperse. Historically, most air pollution studies have been concerned with the effects of recognized chemical materials such as sulfur dioxide, fluorides, ammonia, and carbon monoxide. During the last 10 years a form of air pollution has been observed in some urban areas that differs strikingly from that seen 30 years earlier. This new air pollution is characteristic of modern cities whose economy is based upon the use of petroleum fuels.[9] Some of the gross manifestations of this kind of air pollution are: reduction in visibility, eye irritation, cracking of rubber, elevated atmospheric oxidant levels, and damage to plants. All of these manifestations frequently occur simultaneously and all are associated with photochemical air pollution.

Rubber Cracking

Severe cracking of rubber in the Los Angeles area was early noted by Bradley and Haagen-Smit[2] and an inexpensive ozone test developed based on the cracking of standardized rubber strips. They also showed that rubber cracking identical to that caused by ozone occurred when nitrogen dioxide and sunlight in air were used to oxidize olefins and produce oxidant plant damage. Haagen-Smit, et al.,[12] have elaborated on the use of stressed rubber for the measurement of ozone and have established correlations between high ozone concentrations and photochemical air pollution. Cracking of rubber is common in the Los Angeles, San Diego, and San Francisco areas of California, and has been seen in the vicinity of Honolulu, Hawaii; Phoenix, Ariz.; Washington, D. C.; Wilmington, Del.; Philadelphia, Pa.; Trenton and New Brunswick, N. J.; New York City; Hartford, Conn.; Boston, Mass.; and in rural southern Ontario, Canada.

Oxidant

The occurrence of elevated oxidant whether measured by potassium iodide or by phenolphthalin is another characteristic of photochemical air pollution. Haagen-Smit, et al.,[10] showed that the strong oxidizing effect of the Los Angeles atmosphere was due not only to abnormally high concentrations of ozone but also to peroxides. Haagen-Smit and Brunelle[11] described the application of phenolphthalin to the measurement of oxidant such as ozone, nitrogen oxides, alkyl nitrites, peroxyalkyl nitrites, and a variety of peroxides formed from the oxidation of organic materials, and compared these measurements with those of potassium iodide and rubber cracking. They found that all 3 measurements increase during periods of aggravated photochemical air pollution. Light intensity is an important factor in photochemical oxidation. At low light intensities, such as on overcast days, the ozone and, therefore, total oxidants may be relatively low. Ozone formation in the polluted atmosphere has been shown to consist of a balance between formation and degradation of ozone (Fig. 1). In this photochemical reaction the formation rate of ozone is slightly higher than its rate of decomposition or combination with other reaction products. The slight excess of ozone formed leads, in the case of three methyl heptane, to a steady state condition which lasts for nearly 24 hours. When irradiated mixtures of nitrogen oxides and hydrocarbons are placed in the dark, the excess ozone rapidly decays with a half life of about one hour. At lower light intensities the formation of ozone is decreased while the dark reaction continues to destroy the ozone. Under

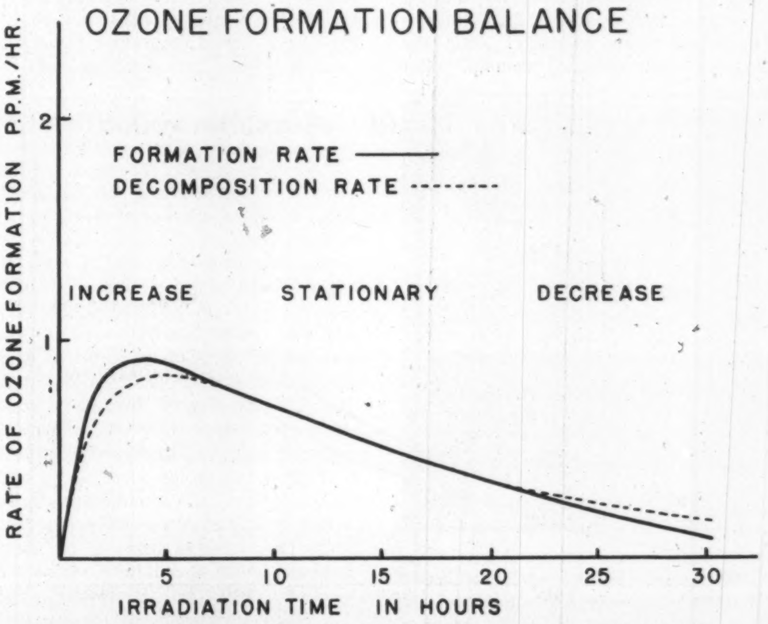

Fig. 1. The balance between formation and degradation of ozone for 3 methyl heptane.

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* Presented at the 53rd Annual Meeting of APCA, Netherland-Hilton Hotel, May 22-26, 1960, Cincinnati, Ohio.

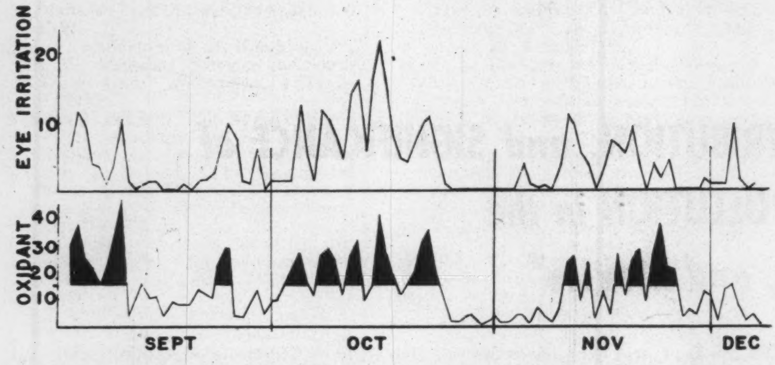

Fig. 2. Comparison between eye irritation and phenolphthalin oxidant expressed as ozone in the Pasadena, Calif., area. The darkened oxidant curve denotes values above the average threshold for initiation of eye irritation at 0.15 ppm.

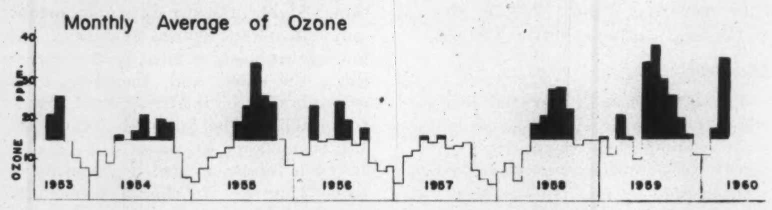

Fig. 3. Monthly average oxidant expressed as ozone as measured by phenolphthalin for the years 1953–1960. Eye irritation usually occurs at levels above 0.15 ppm.

these conditions the total oxidant of which ozone is a major constituent may be relatively low; nevertheless oxidation of the olefins goes on with the production of irritants and aerosols. These facts may explain the lack of rigid correlation of eye irritation and plant damage with oxidants. There is, however, a good qualitative correlation between peaks of irritation and oxidant values as shown in Fig. 2 where results of an eye irritation panel at the Stanford Research Institute and the Air Pollution Foundation are compared with the independently obtained phenolphthalin oxidant values at the California Institute of Technology and the Los Angeles County Arboretum.*

Values for phenolphthalin oxidant maxima expressed as ozone in the Pasadena area for 1953 through March 1960, are given in Fig. 3. These data show that the monthly average ozone ranges from 4 pphm in winter to as high as 38 in summer. Individual daily maxima have reached as high as 90 pphm. Whereas the monthly average for the winter months of 1953 to 1957 have varied from four pphm to eight, they have increased from eight to 10 in 1958 and 1959. A continuous oxidant record makes it possible to see trends, changes, and effectiveness of control programs. For example, the less favorable meteorological conditions for air pollution are shown by lowered oxidant in 1957. The ever-accelerating increase in both hydrocarbons and nitrogen oxides shown in Fig. 4 may account for the increased winter oxidant levels in the last two years.

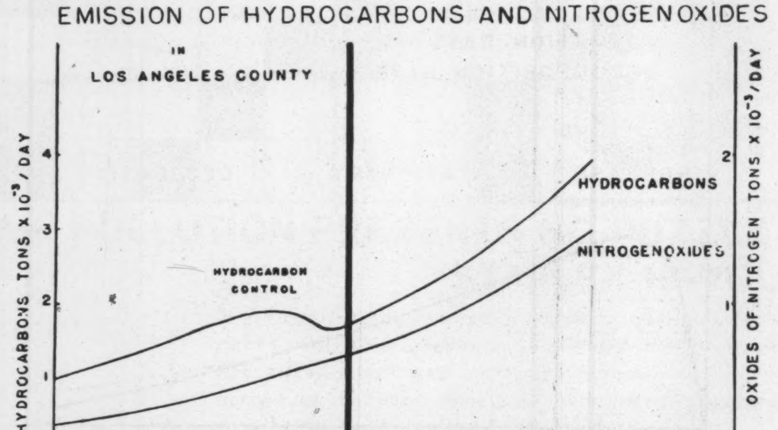

Fig. 4. Emission of hydrocarbons and nitrogen oxides in the Los Angeles area, 1940–1980.

Elevated oxidant values have been found in California throughout the south coastal basin, the San Francisco Bay Area, and in many cities in the San Joaquin and Sacramento Valleys.[24] Elevated oxidant has also been reported by Cholak, et al.,[4] in a number of midwest and eastern cities including: St. Louis, Mo.; Whiting-Hammond, Ind.; Cincinnati, O.; Charleston, W. Va.; Washington, D. C.; and Elizabeth, N. J. Heggestad and Middleton[17] showed oxidant to be elevated at Beltsville, Md.

Plant Damage

Oxidant plant damage due to photochemical air pollution was first observed in the Los Angeles area in 1944 and reported by Middleton, et al.[20] This unique injury is characterized by a glazing and bronzing of the lower leaf surface of susceptible plants. Haagen-Smit, et al.,[13] were the first to demonstrate that the reaction products of ozone and olefins were capable of inducing the injury known to occur naturally in the Los Angeles area. They further showed that the photochemical oxidation of hydrocarbons in the presence of oxides of nitrogen could likewise produce the toxicants responsible for oxidant plant damage. Middleton, et al.[19] described the bleaching and white flecking of the upper leaf surface of leaves due to ozone and showed that neither hydrocarbon nor nitrogen dioxide alone at experienced concentrations are able to cause plant injury symptoms. Oxidant plant injury is common throughout most urban and contiguous rural areas in California and is responsible for significant damage to agricultural crops. Ozone injury to vegetation is not common in California except on especially susceptible plants such as grape,[21] bean, and tobacco. Photochemical air pollution injury to vegetation now occurs in 25 counties of California distributed in the south coastal basin of Los Angeles and San Diego, the San Francisco Bay Area, and the San Joaquin and lower Sacramento portions of the great Central Valley, as shown in Fig. 5. Oxidant

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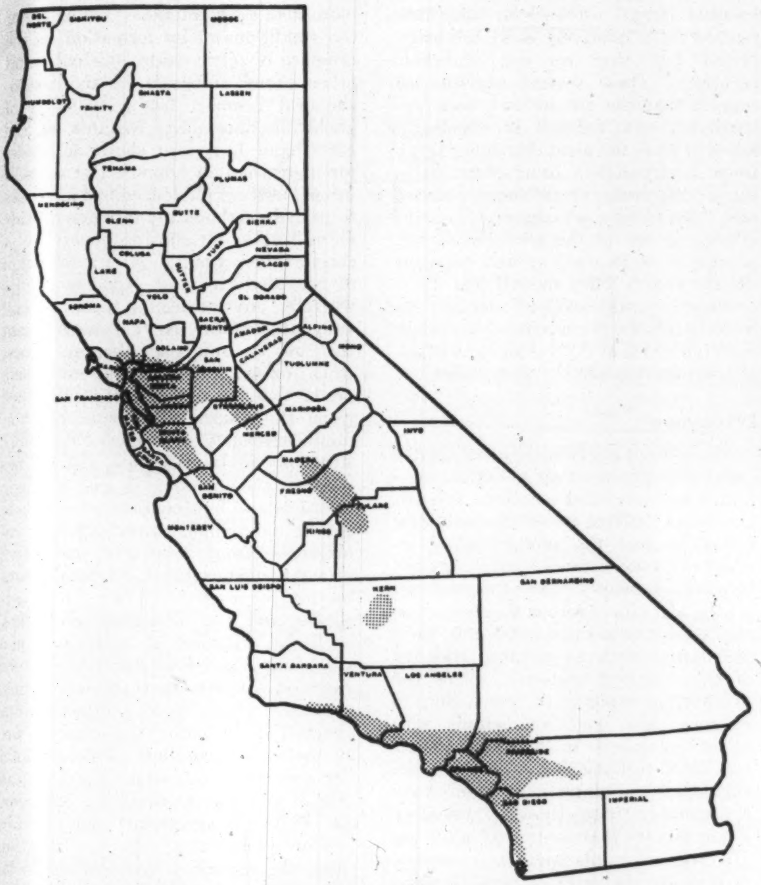
* Courtesy of W. L. Faith of the Air Pollution Foundation, W. S. Stewart of the Los Angeles County and State Arboretum, and Mrs. Juhren of the Los Angeles County Air Pollution Control District.


DEL NORTE
SISKIYOU
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HUMBOLDT
TRINITY
SHASTA
LASSEN
TEHAMA
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COLUSA
YUBA
NEVADA
SUTTER
PLACER
LAKE
YOLO
EL DORADO
SONOMA
NAPA
SACRAMENTO
AMADOR
ALPINE
SOLANO
CALAVERAS
MONO
SAN JOAQUIN
TUOLUMNE
SAN FRANCISCO
STANISLAUS
MARIPOSA
MERCED
SANTA CLARA
INYO
MADERA
FRESNO
SAN BENITO
TULARE
MONTEREY
KINGS
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SANTA BARBARA
VENTURA
LOS ANGELES
RIVERSIDE
SAN DIEGO
IMPERIAL

Fig. 5. Areas in which photochemical plant damage have been identified in California.

damage to plants has been reported by Went[30] from a number of European and South American cities as well as in the United States, at Baltimore, Md.; Philadelphia, Pa.; and New York City. Typical oxidant plant damage now is reported in the western states of Washington, Utah, and Colorado, as well as in northwest coastal Baja California, Mexico. Similar damage has been observed in the midwestern states of Missouri and Illinois. Although oxidant injury occurs in many eastern states, ozone damage seems to be predominant in Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, District of Columbia, and North Carolina.

The difference in plant damage in California compared with that in the Delaware River Valley is rather striking. Spinach and lettuce leaves damaged by photochemical air pollution in California typically show lower leaf surface oxidant-type glazing whereas spinach damaged in the Delaware River Valley typically shows upper leaf surface ozone-type bleaching and flecking, as shown in Figs. 6 and 7. Tobacco grown along the Middle Atlantic Seaboard has shown flecking of the upper leaf surface since 1954. This injury to tobacco was first attributed by Burk and Heggestad[3] to environmental conditions. More recently Heggestad and Middleton[17] have demonstrated that tobacco fleck is incited by ozone, as shown in Fig. 8. Symptoms on tobacco similar to those observed in the eastern states occur on glasshouse-grown tobacco in the Los Angeles area when atmospheric ozone levels are elevated. Macdowall, et al.,[18] reported fleck of tobacco in the Province of Ontario, Canada, where they also demonstrated cracking of rubber, elevated oxidant, and an increased aldehyde concentration in air over tobacco plantations. Although they have as yet been unable to associate the tobacco damage with a specific air contaminant, they nonetheless have determined that the crop injury occurs following recognized weather conditions.

Whereas the determination of rubber cracking, elevated oxidant, and plant damage attributable to ozone has been fairly simple, it has been extremely difficult to specifically identify the chemicals responsible for oxidant values above those due to ozone and nitrogen oxides and oxidant plant damage. The work of Haagen-Smit, et al.,[13] showed that organic acids and aldehydes failed to incite oxidant plant injury; they suggested that peroxidic organic compounds were responsible for this damage. In attempting to further describe the chemicals responsible for oxidant damage, Darley, et al.,[6] studied the effects of ozone-olefin reaction products on plants and suggested that the phytotoxicant was possibly the zwitterion or an ozone-olefin addition complex. Ozonides formed in small amounts in these reactions were relatively stable materials which did not cause oxidant damage to test plants and frequently had little oxidizing effect on potassium iodide. Whatever

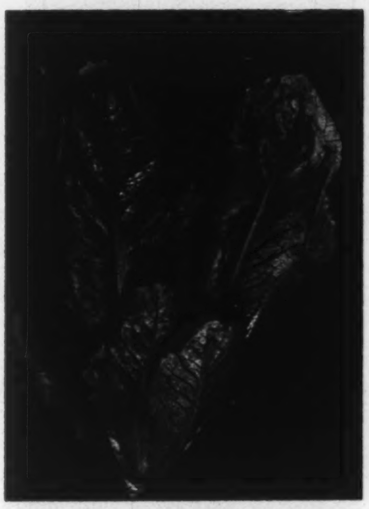

Fig. 6. Oxidant damage to Romaine lettuce showing glazing on the lower leaf surface and freedom from injury on the upper. Material collected in the Los Angeles area, 1956.

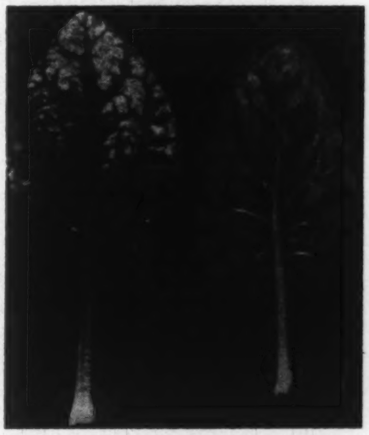

Fig. 7. Ozone injury to spinach grown near Trenton, N. J., and collected October 1959. Left, upper leaf surface showing bleach caused by ozone. Right, no injury to lower leaf surface.

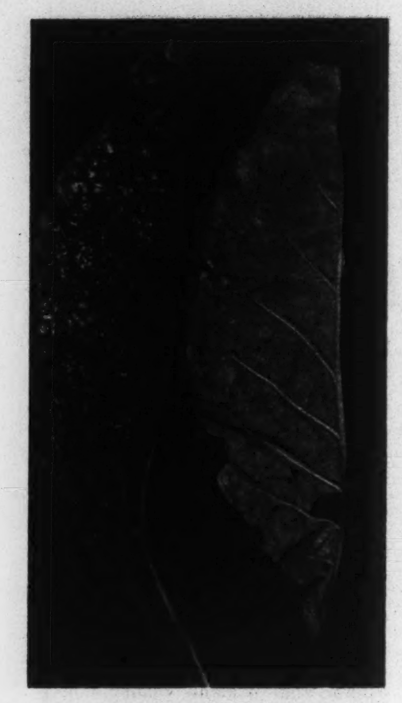

Fig. 8. Connecticut 49 cigar-wrapper tobacco leaf showing, left, ozone fleck on the upper surface and freedom from injury on lower surface. Material collected from field-grown tobacco near Trenton, N. J., October 1959.

the toxic material was, it appeared unstable at low concentrations in air. Arnold[1] studied the longevity of the phytotoxicant produced by two ozone-olefin reactions and showed their half life to be but a few minutes. Schuck[22] and Stephens and Schuck[27] reported eye irritation from irradiation of auto exhaust mixtures and that the irritant was relatively long-lived, while Darley, et al.[5] have shown that plant damage resulted from ozone-olefin mixtures reacted for a relatively short residence period but that no eye irritation occurred. These several experiments suggest that the eye irritant from the irradiated auto exhaust is chemically different than the plant damaging agent from nonirradiated ozone-olefin mixtures. Stephens, et al.[25] have isolated and described peroxyacetyl nitrite (PAN) as one of the products of the photolysis of two-butene and nitrogen dioxide in air. They showed that PAN produces typical oxidant damage to sensitive plants at concentrations below one ppm and that PAN is an eye irritant at concentrations in the ppm range.

Discussion

The concept of chemically and photochemically produced air pollution complexes has furnished solutions to such heretofore baffling problems as ozone formation and the production of irritants at some distance from recognized emission sources. The formulae of Sutton and others permit the estimation of emission concentrations and their distribution with an assumed stability of the dispersed material. Since the material is exposed to the action of oxygen, light, and interactions with other pollutants in addition to atmospheric turbulence and diffusion, the calculated concentrations often vary considerably from those experienced. Other factors that materially alter the kind of pollutants and their concentration are the rates of photochemical production of oxidants.

The olefin-ozone reaction components responsible for plant damage decay quite rapidly after their emission from a point source because the half life of the phytotoxicant is estimated to be no more than a few minutes. Ozone under the conditions of its formation in the presence of nitric oxide, aldehyde, and other ozone acceptors in the photochemical complex has a half life of about one hour. Eye irritants, on the other hand, have been shown to persist for more than 24 hours. The aerosols formed in these photochemical processes from hydrocarbons and nitrogen dioxide as well as sulfur dioxide persist for a considerable time. A fractionation of the photochemical products results whereby phytotoxicants reach a peak value at relatively short distances from the emission source of the precursors, while ozone, eye irritant, and haze production remain high some distance from the source, and concentration diminishes due to atmospheric diffusion. Atmospheric fractionation also occurs because the emission is not a single hydrocarbon but consists of a whole gamut of compounds of different reactivities from relatively unreactive straight chain saturated hydrocarbons to highly reactive olefins. The saturates and the slow-reacting olefins, such as ethylene as well as some oxygenates, have been shown to produce ozone at a slower rate than most olefins, although the peak concentrations reached in laboratory experiments are of the same magnitude as those found for the olefin oxidation, as shown in Fig. 9 and also reported by Stephens, et al.[26] Haagen-Smit[8] has shown oxidant plant damage and eye irritation from the saturated hydrocarbon to be far less than that obtained from olefins. The dynamically reactive, moving, pollution cloud will, therefore, deplete the original emission of reactive olefins with attendant decrease in the formation of oxidant plant damaging factors, eye irritants, oxidants, and aerosols, while the slower reacting saturates, and oxidation products of both saturates and olefins, will continue to produce predominantly oxidants such as ozone and haze for a considerable distance away from the source.

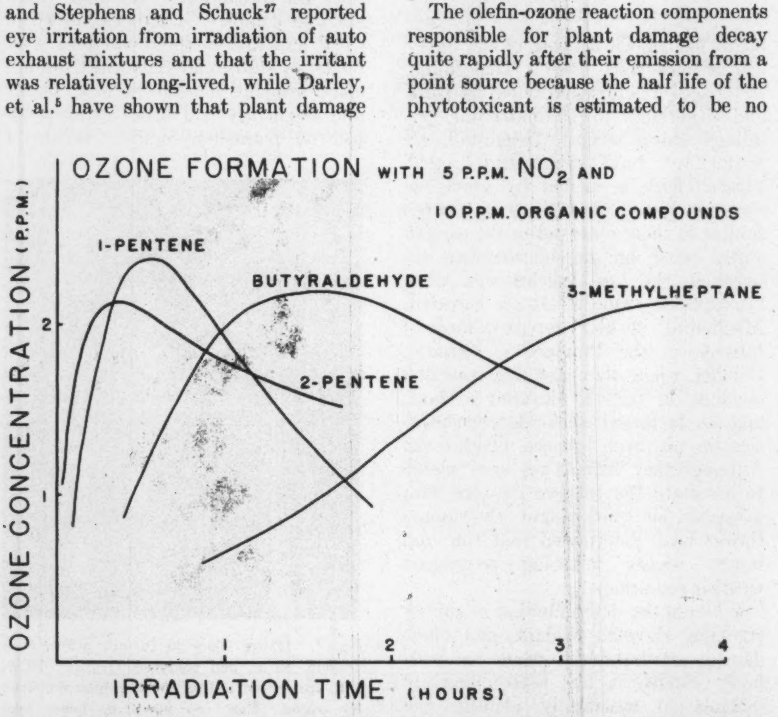

Fig. 9. Concentration and rate of ozone formation with organic compounds and nitrogen dioxide.

The fractionation processes with distance from an emission source and the rapid decay of the olefin content of the polluted air have been experimentally established by mass spectrographic analyses of Shepherd, et al.[23] and Weaver, et al.[29] The peak ozone concentrations obtained from olefins and saturates have been shown to be nearly the same while the rate of formation is dissimilar. The lower limits for the formation of ozone from the two types of compounds are markedly different. Figures "a" and "b" as published by Haagen-Smit and Fox[14] show that ozone forms from 1.0 ppm of the saturated three methyl heptane at the very low concentration of 0.05 ppm nitrogen dioxide whereas the first indication of ozone appearance from the olefin 2-

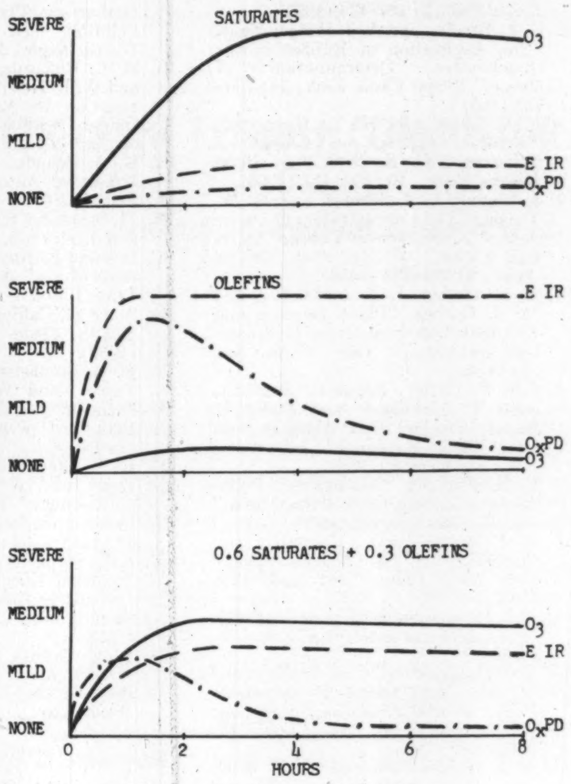

Fig. 10. Time sequence for predicted severity of some photochemical air pollution manifestations resulting from photolysis of nitrogen dioxide and hydrocarbons. The symbol O_3 represents ozone; E IR represents eye irritation; and O_xPD represents oxidant plant damage.

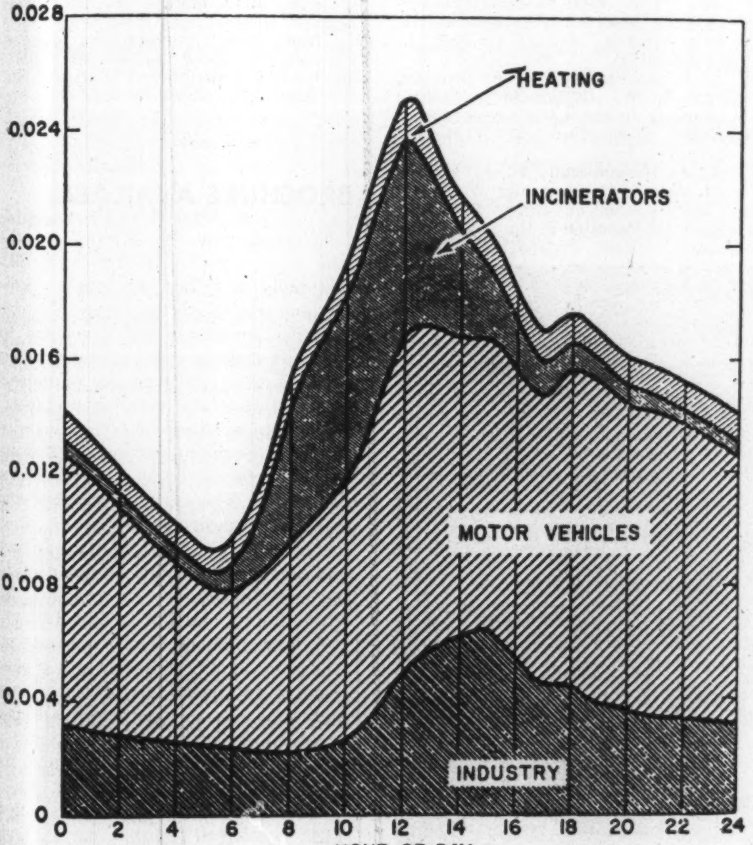

Fig. 11. Relative contribution of the selected four principal pollutant sources in 1954 to the mean contribution in the Los Angeles area based on a mathematical model by F. N. Frenkiel.

butene at 1.0 ppm is at the higher concentration of 0.4 ppm. This phenomena is attributed to the ready acceptance of the olefin of ozone and the resistance of the saturate to ozone. This was also the reason why three methyl heptane was chosen for the initial experiments demonstrating the formation of ozone in the photochemical oxidation of hydrocarbons. The rubber used as an ozone indicator also scavenged ozone from the system in a manner analogous to the scavenging occurring in ambient air. Olefins are attacked at concentrations below 0.4 ppm nitrogen dioxide as evidenced by the formation of eye irritants and phytotoxicants.

The different aspects of the photochemical syndrome over an extended area and at different centers of pollution arise from the relative rate of decay of the irritants, the oxidative fractionation process of rapid and slow precursors, and the injection of new materials such as organics and nitrogen oxides into the moving cloud. In a well-defined area of pollution without additional injections of contaminants in the path of the pollution cloud, medium eye irritation, oxidant plant damage, and low oxidant values near the source would be expected. After a few hours of travel, the ozone level would become high while eye irritation would remain medium. At the same time oxidant plant damage would decrease considerably. After a longer time period and at greater distance from the source with low nitrogen oxides, high ozone concentrations and eye irritation would be noticeable but no oxidant plant damage. These predictions would be modified by the diffusion of the pollution cloud which would lower the concentration of the pollutants. This situation may prevail in Connecticut where ozone damage on tobacco is disturbing while no oxidant damage is noticed. The occurrence of oxidant plant damage in and around Washington, D. C., and the occurrence of ozone damage on tobacco some distance from there is explained by the fractionation of the moving pollution cloud which Wanta and Heggestad[28] report, on the basis of meteorological information, as moving away from Washington. The severity of some of these manifestations as a function of type of hydrocarbon and length of photolysis is graphically presented in Fig. 10.

The prevalence of ozone injury to plants in the upper Delaware River Valley may be similarly accounted for by the movement of the pollution cloud away from metropolitan Philadelphia without injection of much additional precursors en route.

In extended urban areas, such as Los Angeles and San Francisco and their surrounding communities, many new sources of emission of both hydrocarbons, nitrogen oxides, as well as sulfur dioxide from automobiles and other fuel combustion, together with industrial and domestic activities will continue to inject new smog precursors into the moving, dynamic chemical, and photochemical system. Under this situation of a nearly continuous area of pollution from motor vehicles, oxidant plant injury, eye irritation, elevated oxidant, rubber cracking, and haze formation appear generally throughout the afflicted airshed.

The cracking of rubber, the production of elevated oxidant, and the occurrence of both ozone and oxidant plant damage have all been shown to be manifestations of photochemical air pollution. These manifestations result from ozone produced in the photochemical oxidation of 54 organic compounds in the presence of oxides of nitrogen, as demonstrated by Haagen-Smit and Fox,[15] and by the formation of ozone and peroxyacetyl nitrite from the photolysis of auto-exhaust-type olefins and oxides of nitrogen as demonstrated by Stephens, et al.[25] These two toxicants have been produced in well controlled photochemical experiments using auto exhaust olefins, nitrogen dioxide, and air. They have also been identified as reaction products of irradiated auto exhaust, and are found in polluted air in the Los Angeles area.

The raw materials which permit the manufacture of ozone and PAN result from man's industrial, urban, and domestic activities. Frenkiel[7] presents a striking graphic illustration of a mathematical model of Los Angeles in which the motor vehicle provides the largest proportion of pollutants in 1954, see Fig. 11. The development of alternative disposal methods for industrial and domestic organic wastes essentially eliminates the pollution contribution of the incinerator and thereby emphasizes the contribution of the motor vehicle. The contribution of the motor vehicle to the problem is further pointed up by the steady increase in carbon monoxide levels in Los Angeles.[16] The adoption by the California State Board of Health[24] of motor vehicle exhaust contaminant standards for hydrocarbons of 0.165 mole % carbon atoms and carbon monoxide of 1.5%, and ambient air standards of 0.15 ppm oxidant (potassium iodide) as the adverse level for photochemical air pollution was made to reduce motor vehicle exhaust emissions and improve air quality in California. Control of motor vehicle exhaust must be achieved if air is to be conserved as an essential national natural resource.

REFERENCES

1. Wilfred Niels Arnold, "The Longevity of the Phytotoxicant Produced from Gaseous Ozone-Olefin Reaction," *Int. J. Air Poll.*, **2**: 167–174 (1959).
2. C. E. Bradley and A. J. Haagen-Smit, "The Application of Rubber in the Quantitative Determination of Ozone," *Rubber Chem. Tech.*, **24**: 750–753 (1951).
3. L. G. Burk and H. E. Heggestad, "Weather Fleck on Nicotiana Tabacum," *U. S. Dept. Agr. Plant Disease Reptr.*, **40**: 424–427 (1956).
4. J. Cholak, L. J. Schafer, and D. W. Yeager, "The Concentration of Ozone in the Atmosphere of Certain American Cities," *J. Air Poll. Control Assoc.*, **5**: 227–232 (1956).
5. E. F. Darley, J. T. Middleton, and M. J. Garber, "Plant Damage and Eye Irritation from Ozone-Hydrocarbon Reactions," *Amer. Chem. Soc.* (In Press).
6. Ellis F. Darley, Edgar R. Stephens, John T. Middleton, and Philip L. Hanst, "Oxidant Plant Damage from Ozone-Olefin Reactions," *Int. J. Air Poll.*, **1**: 155–162 (1959).
7. F. N. Frenkiel, "Atmospheric Pollution and Zoning in an Urban Area," *Sci. Mo.*, **82**: 194–203 (1956).
8. A. J. Haagen-Smit, "Chemistry and Physiology of Los Angeles Smog," *Ind. Eng. Chem.*, **44**: 1342–1346 (1952).
9. A. J. Haagen-Smit, "Urban Air Pollution," *Advances in Geophysics*, **6**: 1–18 (1959).
10. A. J. Haagen-Smit, C. E. Bradley, and M. M. Fox, "Ozone Formation in Photochemical Oxidation of Organic Substances," *Ind. Eng. Chem.*, **45**: 2086–2089 (1953).
11. A. J. Haagen-Smit and M. F. Brunelle, "The Application of Phenolphthalin Reagent to Atmospheric Oxidant Analysis," *Int. J. Air Poll.*, **1**: 51–59 (1958).
12. A. J. Haagen-Smit, M. F. Brunelle, and J. W. Haagen-Smit, "Ozone Cracking in the Los Angeles Area," *Rubber Chem. Tech.*, **32**: 1134–1142 (1959).
13. A. J. Haagen-Smit, E. F. Darley, M. Zaitlin, H. Hull, and W. Noble, "Investigation on Injury to Plants from Air Pollution in the Los Angeles Area," *Plant Physiol.* **27**: 18–34 (1952).
14. A. J. Haagen-Smit and Margaret M. Fox, "Automobile Exhaust and Ozone Formation," *Soc. of Auto. Eng. Trans.*, **63**: 575–580 (1955).
15. A. J. Haagen-Smit and M. M. Fox, "Ozone Formation in Photochemical Oxidation of Organic Substances," *Ind. Eng. Chem.*, **48**: 1484–1487 (1956).
16. W. J. Hamming, R. D. MacPhee, and J. R. Taylor, "Contaminant Concentrations in the Atmosphere of Los Angeles County," *J. Air Poll. Control Assoc.*, **10**: 7–16 (1960).
17. Howard E. Heggestad and John T. Middleton, "Ozone in High Concentrations as Cause of Tobacco Leaf Injury," *Science*, **129**: 208–210 (1959).
18. The authors wish to thank F. D. H. Macdowall, Canada Department of Agriculture; V. C. Runeckles, Imperial Tobacco Company of Canada, Ltd.; and B. C. Newbury, Ontario Research Foundation, for their kindness in supplying information on rubber cracking, oxidant levels, and tobacco fleck.
19. John T. Middleton, Ellis F. Darley, and Robert F. Brewer, "Damage to Vegetation from Polluted Atmospheres," *J. Air Poll. Control Assoc.*, **8**: 9–15 (1958).
20. John T. Middleton, J. B. Kendrick, Jr., and H. W. Schwalm, "Injury to Herbaceous Plants by Smog or Air Pollution," *U. S. Dept. Agr. Plant Disease Reptr.*, **34**: 245–252 (1950).
21. B. L. Richards, John T. Middleton, and W. B. Hewitt, "Air Pollution with Relation to Agronomic Crops: V. Oxidant Stipple of Grape," *Agron. J.*, **50**: 559–561 (1958).
22. E. A. Schuck, "Eye Irritation from Irradiated Auto Exhaust," *Air Poll. Found.*, 2(6): 1–85 (1957).
23. M. Shepherd, S. M. Rock, R. Howard, and J. Stormes, "Isolation, Identification and Estimation of Gaseous Pollutants of Air," *Analyt. Chem.*, **23**: 1431–1434 (1951).
24. State of California, Dept. of Public Health, *Clean Air Quart.*, **3**: 23–25 (1959).
25. E. R. Stephens, E. F. Darley, O. C. Taylor, and W. E. Scott, "Photochemical Reaction Products in Air Pollution," *Proc. Amer. Petrol. Inst.* (In Press).
26. E. R. Stephens, P. L. Hanst, R. C. Doerr, and W. E. Scott, "Reactions of Nitrogen Dioxide and Organic Compounds in Air," *Ind. Eng. Chem.*, **48**: 1498–1504 (1956).
27. E. R. Stephens and E. A. Schuck, "Air Pollution Effects of Irradiated Auto Exhaust as Related to Fuel Composition," *Chem. Eng. Prog.*, **54**: 71–77 (1958).
28. R. C. Wanta and H. E. Heggestad, "Occurrence of High Ozone Concentrations in the Air near Metropolitan Washington," *Science*, **130**: 103–104 (1959).
29. E. R. Weaver, E. E. Hughes, S. M. Gunther, S. Schuhmann, N. T. Redfearn, and R. Gorden, Jr., "Interpretation of Mass Spectra of Condensates from Urban Atmospheres," *J. Res. Nat. Bur. Stand.*, **59**: 383–404 (1957).
30. F. W. Went, "Air Pollution," *Sci. Amer.*, **192**: 62–70, 72 (1955).

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NONCATALYTIC *Auto Exhaust* COMBUSTOR

CHARLES H. WORSHAM, ROBERT B. LONG, and JOHN P. LONGWELL, Esso Research and Engineering Company, Linden, N. J.

It is generally agreed[1-4] that unburned fuel present in auto exhaust is one of the major contributors to the Los Angeles air pollution problem. Consequently, considerable research effort[5-7] is being directed toward preventing hydrocarbon emission in general from autos and toward removing unburned or partially burned fuel from the exhaust in particular. This latter approach makes use of either catalytic or thermal afterburners. Catalytic afterburners are attractive because of their ability to operate at relatively low exhaust temperatures. However, they present a problem in getting long enough catalyst life when burning exhaust from leaded fuels. Thus, an efficient thermal afterburner might have several advantages over a catalytic unit. These considerations led to our brief study of a simple thermal afterburner which was tested on an auto engine burning commercial leaded fuel.

Apparatus and Procedure

Thermal Afterburner

The noncatalytic combustion of auto exhaust gases was demonstrated using a commercial leaded gasoline and a 1954 Chevrolet engine test stand. The combustor consisted of a stainless steel heat exchanger attached to the engine exhaust manifold. Both manifold and exchanger were insulated to conserve heat. The oxygen, carbon monoxide, and carbon dioxide contents of the combustion products were measured with continuous gas analyzers and the hydrocarbon content was determined by mass spectrometer on spot samples taken from the combustor outlet. The equipment set-up is shown in Fig. 1.

Operation of the combustor is self-sustaining once the exhaust gases have been ignited. Heat is furnished from the combustion of carbon monoxide, hydrocarbons, and hydrogen, with excess room temperature air added into the exhaust manifold near each of the exhaust gas ports. The air added amounted to three to five percent O_2 based on the exhaust volume and was metered through rotameters. The hot gases leaving the combustion zone in the exchanger help heat the exhaust gases entering countercurrently from the engine manifold as shown in Fig. 2.

The exchanger consists of a jacketed fin-tube. The entering pipe is $1^{1}/_{2}$ in. diam by four feet long, having fins inside and outside for heat transfer. This pipe is inside of a four-inch diam pipe through which the gases return and are exhausted. The exchanger is insulated with regular asbestos insulation about 2.5 in. in thickness. The pressure drop through this heat exchanger was very small and varied from 0.03 in. of mercury at 500 rpm to 0.22 in. of mercury at 3000 rpm.

The exhaust gases were ignited by running the engine at 3000 to 3500 rpm for about 10 minutes to heat the exchanger to about 1400°F. Once so ignited, the exhaust continues to burn in the heat exchanger even with the engine idling at 500 rpm.

Reactor for Pilot Studies

The design of the heat exchanger was based on data obtained in a pilot reactor using synthetic exhausts. A sketch of this reactor is shown in Fig. 3. This equipment consists of an insulated $1^{1}/_{2}$-in. diam stainless steel pipe 10 feet long provided with a preheater and packed with stainless steel crinkled wire mesh. This unit was built to provide kinetic data at minimum auto exhaust rates. Instruments were attached for measuring temperatures and oxygen, carbon monoxide, and carbon dioxide contents of the gas stream at various points in the reactor as shown. The nitrogen is preheated. The oxygen and butane are added before the reactor through a mixing zone.

Pilot Studies to Obtain Fundamental Data

Pilot studies in the $1^{1}/_{2}$-in. diam reactor were confined to simulated exhausts consisting of 0.2 to 0.9% n-butane in nitrogen containing sufficient oxygen for combustion. The effects of temperature and gas velocity on the combustion characteristics were

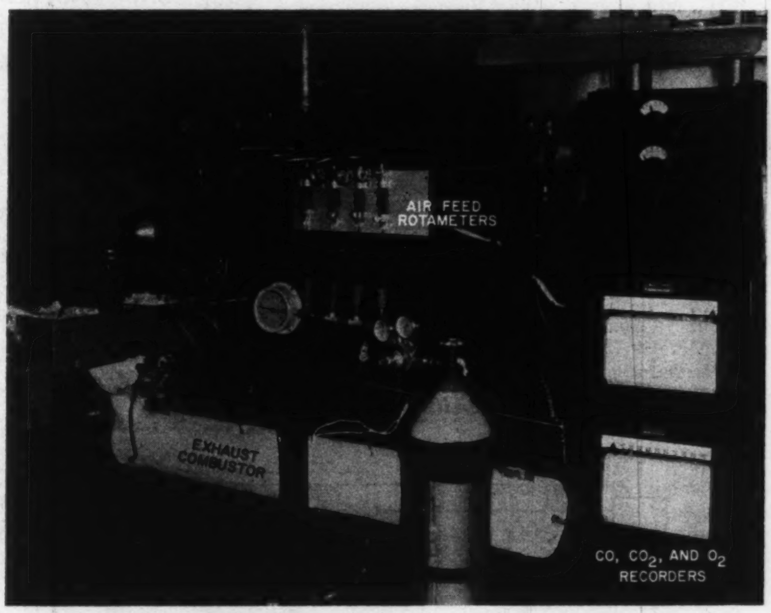

Fig. 1. Exhaust combustor attached to Chevrolet engine manifold.

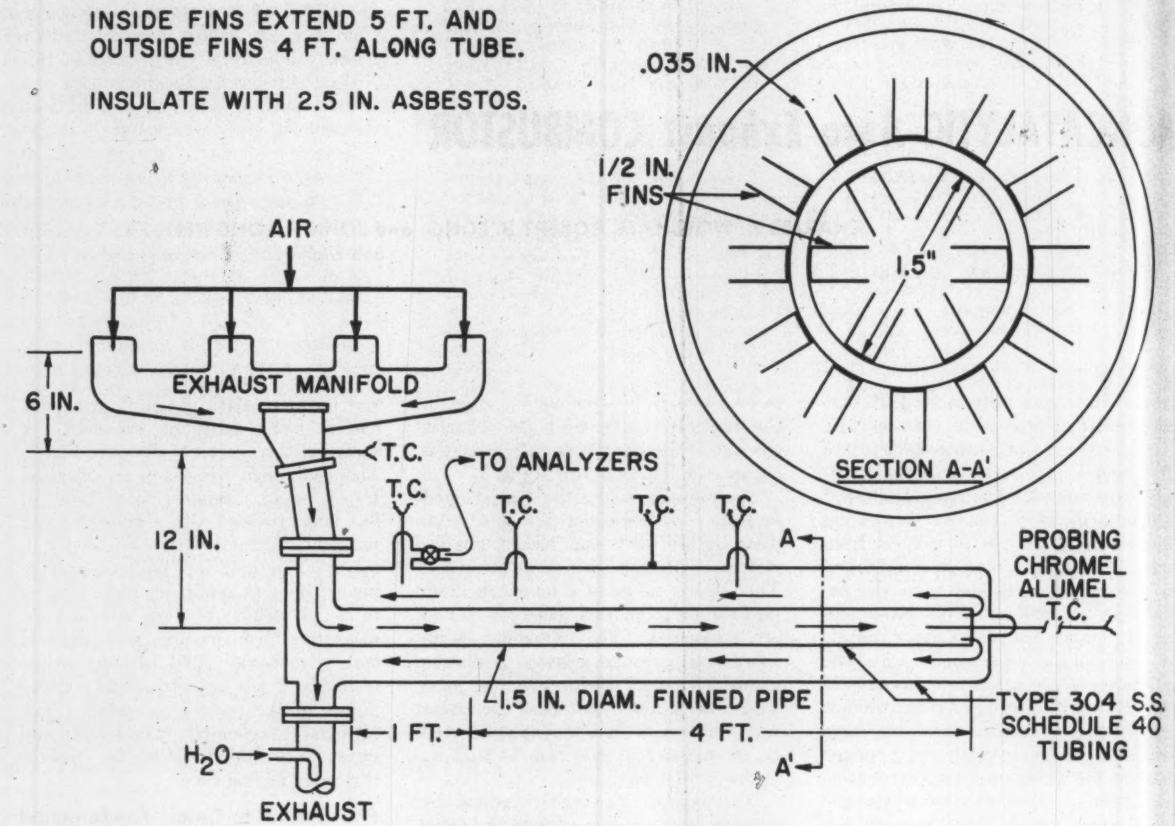
INSIDE FINS EXTEND 5 FT. AND
OUTSIDE FINS 4 FT. ALONG TUBE.
INSULATE WITH 2.5 IN. ASBESTOS.
.035 IN.
1/2 IN.
FINS
1.5"
SECTION A-A'
AIR
EXHAUST MANIFOLD
6 IN.
12 IN.
T.C.
TO ANALYZERS
T.C.
T.C.
T.C.
T.C.
A
PROBING
CHROMEL
ALUMEL
T.C.
1.5 IN. DIAM. FINNED PIPE
TYPE 304 S.S.
SCHEDULE 40
TUBING
H_2O
1 FT.
4 FT.
A'
EXHAUST

Fig. 2. Schematic diagram of heat exchanger.

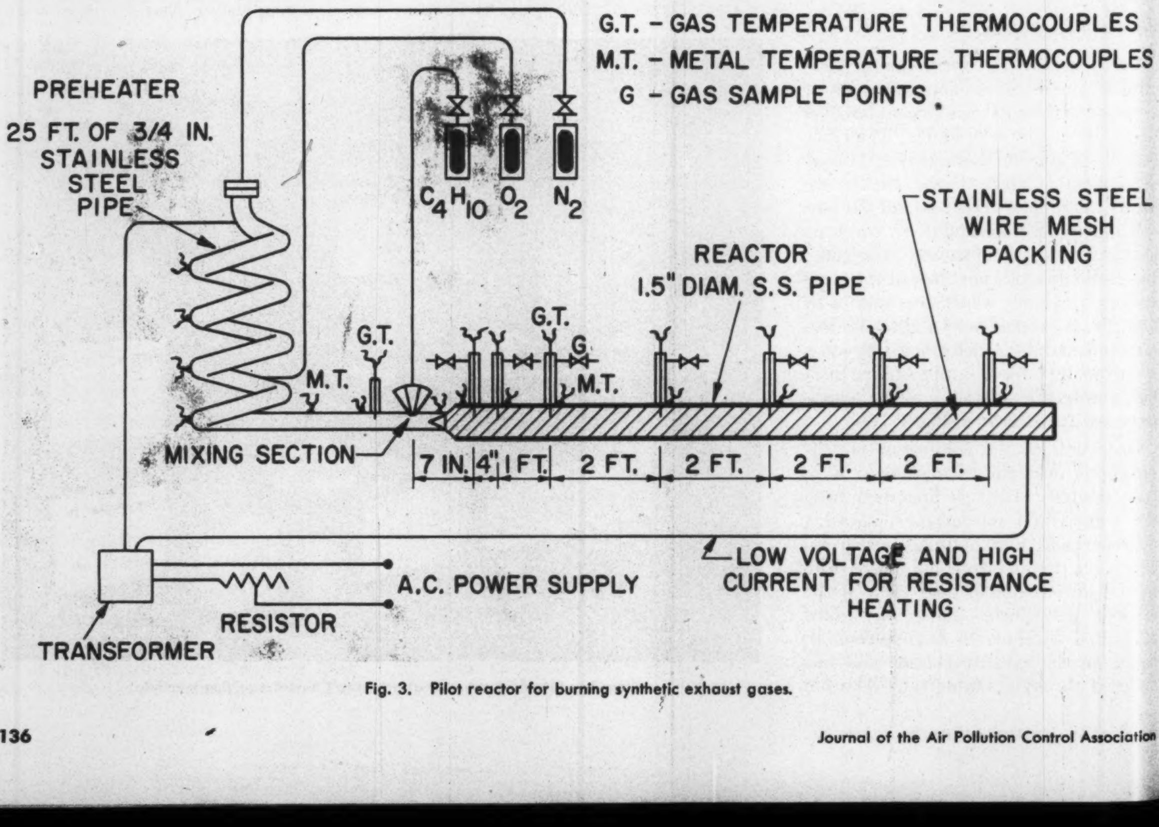
G.T. - GAS TEMPERATURE THERMOCOUPLES
M.T. - METAL TEMPERATURE THERMOCOUPLES
G - GAS SAMPLE POINTS
PREHEATER
25 FT. OF 3/4 IN.
STAINLESS
STEEL
PIPE
C_4H_{10}
O_2
N_2
STAINLESS STEEL
WIRE MESH
PACKING
REACTOR
1.5" DIAM. S.S. PIPE
G.T.
G.T.
G
M.T.
M.T.
MIXING SECTION
7 IN.
4"
1 FT.
2 FT.
2 FT.
2 FT.
2 FT.
LOW VOLTAGE AND HIGH
CURRENT FOR RESISTANCE
HEATING
A.C. POWER SUPPLY
RESISTOR
TRANSFORMER

Fig. 3. Pilot reactor for burning synthetic exhaust gases.

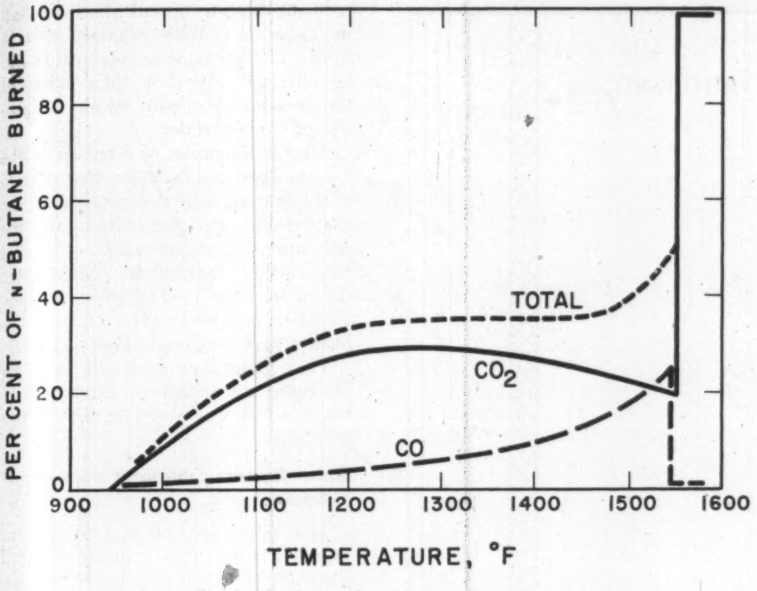

Fig. 4. Oxidation of n-butane in pilot reactor.

Component	Vol. %	Cu ft/hr
Nitrogen	96.7	213
Oxygen	3.0	6.6
n-Butane	0.3	0.62
	Total	220

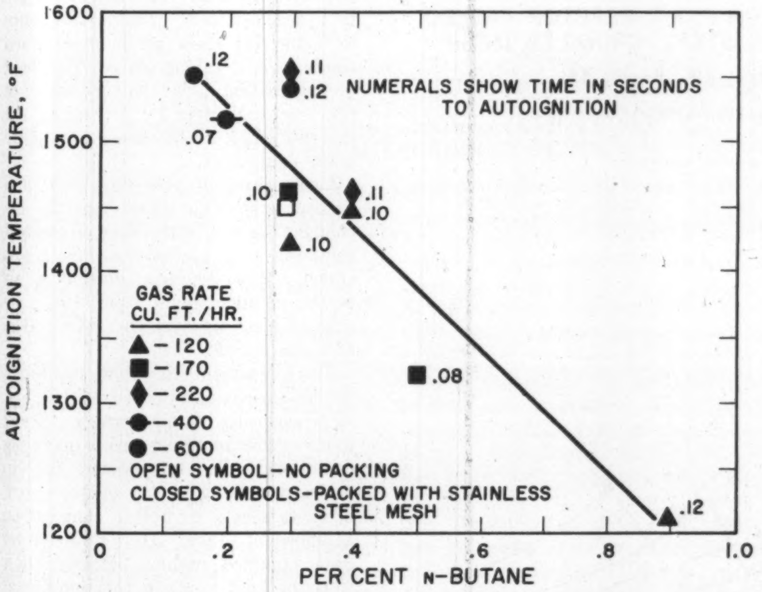

Fig. 5. Autoignition temperature of n-butane in pilot reactor; simulated exhaust: n-butane in nitrogen containing 3% oxygen.

Table II

Mole Ratio of O_2 to n-Butane		n-Butane Burned, %, for	
Actually Used	Theoretical for Reaction to	0.3% C_4 in Gas	0.9% C_4 in Gas
6.5	$CO_2 + H_2O$	100	100
4.0	$CO_2 + H_2$	80	100
2.0	$CO + H_2$	60	100
1.0	—	50	50

Table I

Gas Approach Velocity at 1300°F, Ft/Sec	Percent of n-Butane Oxidized to CO and at 1300°F
5	60
10	50
20[a]	30
30[a]	10
40[a]	2

[a] Idling velocity of gases from auto engine.

determined.

These experiments have shown that oxidation of n-butane in the simulated exhaust begins at temperatures of about 900 to 1100°F, as evidenced by carbon monoxide and carbon dioxide formation. The amount of butane oxidized was found to reach a plateau as temperature increased until the autoignition temperature was reached. At this point combustion became complete. This is demonstrated for a simulated exhaust of 0.3% n-butane and three percent oxygen in nitrogen in Fig. 4.

The amount of n-butane oxidized in the partial oxidation plateau depends upon the operating conditions—mainly the gas velocity. Typical data are shown in Table I for 1300°F inlet temperature. The amount of n-butane oxidized decreases with increased gas velocity and also depends on the available surface. Packing the reactor with stainless steel crinkled wire mesh approximately doubles the amount of butane oxidized over a wide range of flow rates. These data suggest the possibility of a surface catalyzed process for these preignition reactions. Mass spectrometer analyses show that about 20 to 35% butane cracking also occurs at 1300–1400°F.

Ignition Temperature Depends on Composition

The autoignition temperature is dependent mainly on the concentration of n-butane in the gas and is independent of gas velocity over the range of gas velocities studied. It decreases with increased n-butane concentration as shown in Fig. 5 and is insensitive to the presence or absence of wire mesh packing.

Appreciable cracking of n-butane precedes autoignition. However, unlike the ignition temperature, the degree of cracking depends on the contact time as shown in Fig. 6.

Oxygen Requirements Are Low

In experiments with approach gas temperatures above the autoignition point, it has been found that the n-butane can be completely destroyed with much less oxygen than is theoretically required for complete combustion to CO_2 and H_2O. The effect of

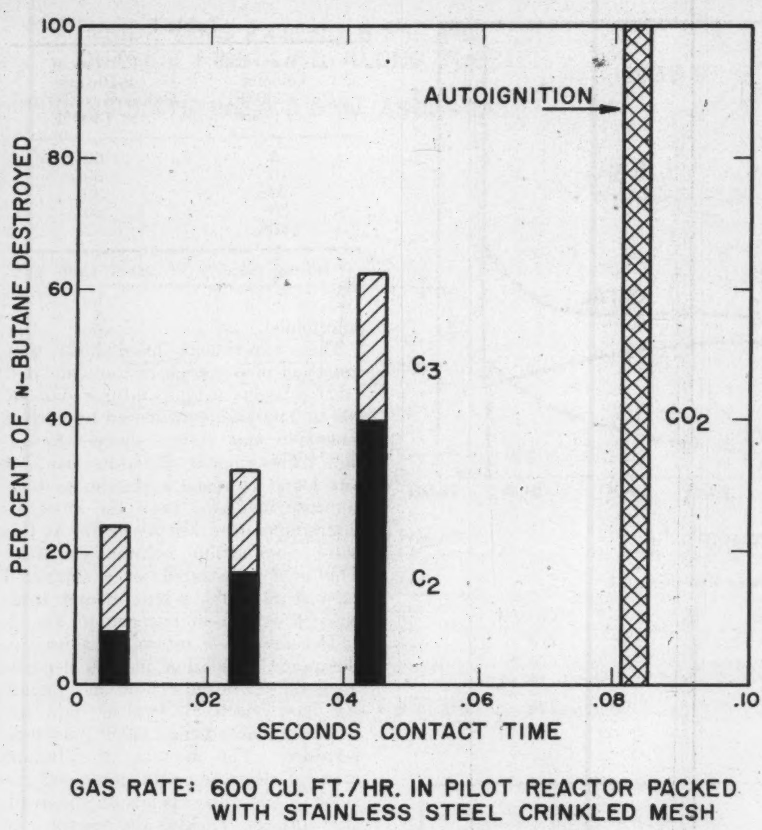

Fig. 6. n-Butane cracks prior to autoignition.

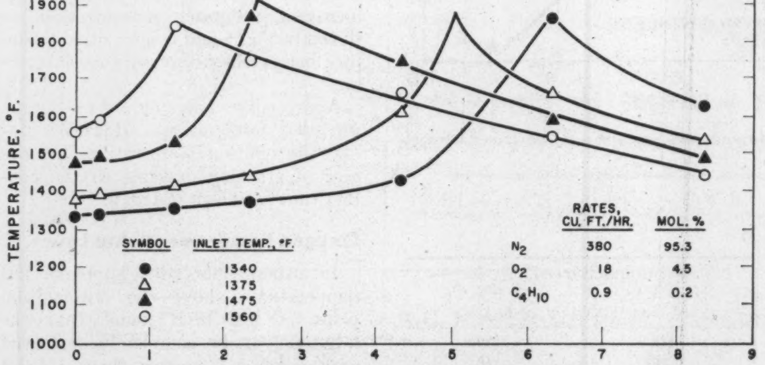

Fig. 7. Butane combustion temperature patterns; complete combustion ignition temperature = 1510°F.

reducing oxygen concentration is shown in Table II. With exhausts rich in hydrocarbon, complete combustion can be obtained with less than one-third the theoretical amount of air for producing CO_2 and water.

After autoignition of n-butane in the $1^1/_2$-in. diam reactor pipe, the location of the burning zone is dependent on the gas velocity, gas composition, and the gas approach temperature. Typical temperature distribution patterns are shown in Fig. 7. The effect of these variables on the location of the combustion zone is shown in Figs. 8 and 9.

These data were used as a basis for designing the prototype exhaust combustor which was tested on the Chevrolet engine.

Good Results Obtained on Actual Exhausts

The prototype exhaust combustor[4] attached to the engine running on leaded gasoline gave total removal of the carbon monoxide and hydrogen, and greater than 70% removal of hydrocarbons over a wide range of engine speeds as is shown in Table III. The hydrocarbons remaining in the exhaust are less than 0.1% which may be at about the detection threshold of the mass spectrometer used. Accordingly, more complete removal of the hydrocarbons may actually have been accomplished. The temperatures in Table III show an increase when combustion is taking place. This heat of combustion aids the operation of the heat exchanger by preheating the exhaust gases as discussed previously under equipment.

Comparison of the data with and without added air shows that the exchanger has very little effect on exhaust composition at low speeds if no air is added. However, the addition of air to the manifold gives about the same exhaust clean-up over the entire range of engine speeds.

The temperature distribution through the heat exchanger is illustrated in Fig. 10 when using air for burning. These temperatures represent steady operating conditions. The temperature pattern varies depending on the engine speed, or exhaust rate, as well as composition as shown in Table III. Temperature data obtained without ignition show that the heat losses in this combustor are such that about 50% of the heat of combustion was lost through the insulation. Thus, better insulation would give higher combustion temperatures.

The location of the burning front in the exchanger is dependent on temperature and contact time. At 3000 rpm most of the combustion occurs near the heat exchanger entrance or in the exhaust manifold as evidenced by a high initial temperature; whereas at 500 rpm a large portion of the combustion takes place towards the return

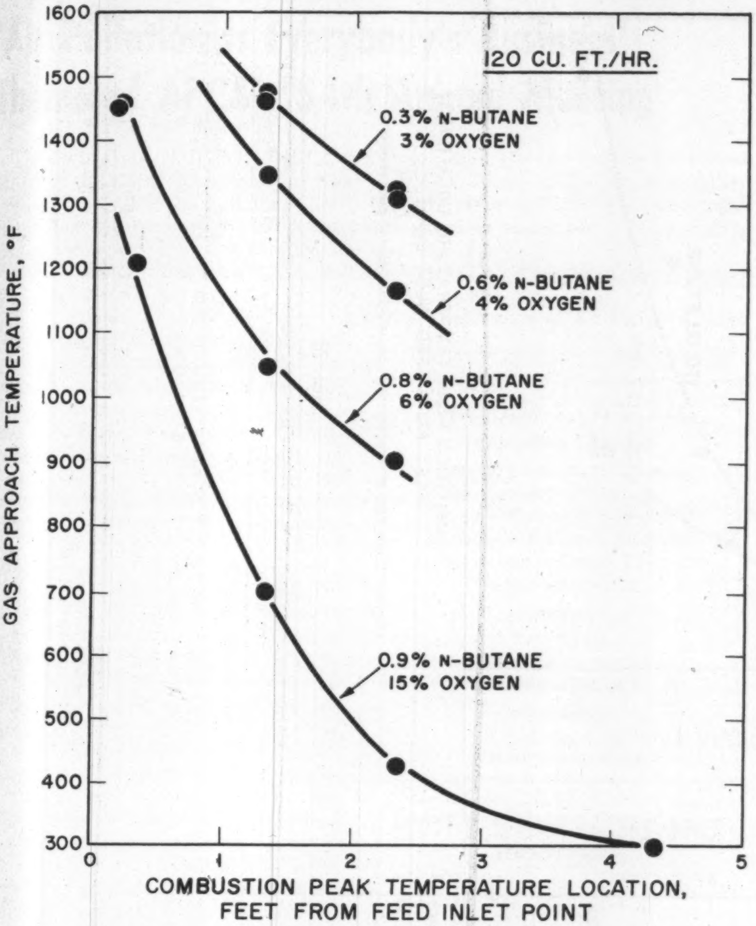

Fig. 8. The effect of gas composition on butane combustion in the pilot reactor.

bend of the heat exchanger as evidenced by the rapid rise at about the five-foot point. The earlier rise at the two- to three-foot point is apparently caused by heat exchange and possibly some preignition oxidation of H_2 and hydrocarbons. In general, the data obtained with the combustor agreed with predictions made from the pilot reactor.

In the final design of an exhaust combustor heat exchanger, many engineering variations are possible. However, the following features are felt to be desirable in a good design.

1. Means for the addition of air to the exhaust gases between the exhaust manifold and heat exchanger.
2. Good insulation to minimize the warm-up time.
3. Good gas-to-gas heat exchange.
4. Preheat of the air added to the heat exchanger.
5. An auxiliary ignition system to ignite the exhaust more quickly at start-up.

There are compensating factors that aid in the design of the heat exchanger. At high engine speeds the contact time is short, but more heat is supplied in the exhaust gases. At low engine speeds the exhaust temperature is low, but the hold-up time is greater. These compensating factors make it possible to design a single heat exchanger suitable for various engine operating conditions. An exchanger with a greater hold-up time than used in these experiments may be needed at higher engine speeds and load conditions. However, as a result of the experiments reported here, it is felt that a satisfactory noncatalytic exhaust combustor can be developed.

Acknowledgment

The authors wish to thank the Esso Research and Engineering Company for permission to publish this paper and to acknowledge the advice of Professor H. C. Hottel who originally suggested the possibility of the countercurrent heat exchanger as an exhaust combustor design.

REFERENCES

1. R. L. Chass, R. G. Lunche, N. R. Shaffer, and P. S. Tow, Paper 59-58 APCA 52nd Annual Meeting (June 1959).
2. Second Technical and Administrative Report on Air Pollution Control in Los Angeles County 1950–51. Air Pollution Control District, County of Los Angeles, p. 28.
3. A. J. Haagen-Smit, E. F. Darley, M. Laithlin, H. Hall, and W. M. Noble, *Plant Physiology* **27**: 1, 18–34 (January 1952).
4. E. R. Stephens and E. A. Schuck, *Ch. Eng. Prog.* **54**: 11, 71 (November 1958).
5. W. Linville, R. G. Holmes, and C. V. Kanter, *J. Air Poll. Control Assoc.* **10**: 21 (1960).
6. S. L. Ridgway, "Homogeneous Reaction Kinetics and the Afterburner Problem," presented at SAE Detroit Annual Meeting (Jan. 12–16, 1959).
7. *Oil and Gas Journal* **57**: 45, 48 (Nov. 2, 1959).

(See Figs. 9 & 10 & Table III on next page)

METEOROLOGICAL SOCIETY RELEASES STATEMENT CONCERNING SATELLITES

The American Meteorological Society, very conscious of the great public interest in meteorological satellites placed in orbit by the United States, has devoted two full scientific sessions of its national meeting now in progress in New York City discussing the scientific results being derived from the satellite observations. It is the desire of the Society to keep the press and, through them, the public, currently informed on these important matters and to this end the Council of the Society approved the following statement:

AMS Statement on Meteorological Satellites

The success of recent satellite experiments in obtaining television pictures of cloud patterns and in measuring various physical properties of the earth's atmosphere has prompted a great deal of speculation, some earnest and some fanciful, about the effects which these and future satellites will have on the accuracy of weather forecasts. The purpose of this statement is to make public the opinion of the American Meteorological Society on this subject.

Scientific weather forecasting depends basically on two factors: timely knowledge of current atmospheric conditions over the earth, and technical knowledge as to how atmospheric processes will alter these conditions. Science has made considerable progress in understanding the processes of weather changes. On the other hand, there remain great gaps in observations of current weather conditions over large areas of the globe, especially over the oceans, the tropics, and other uninhabited or undeveloped regions.

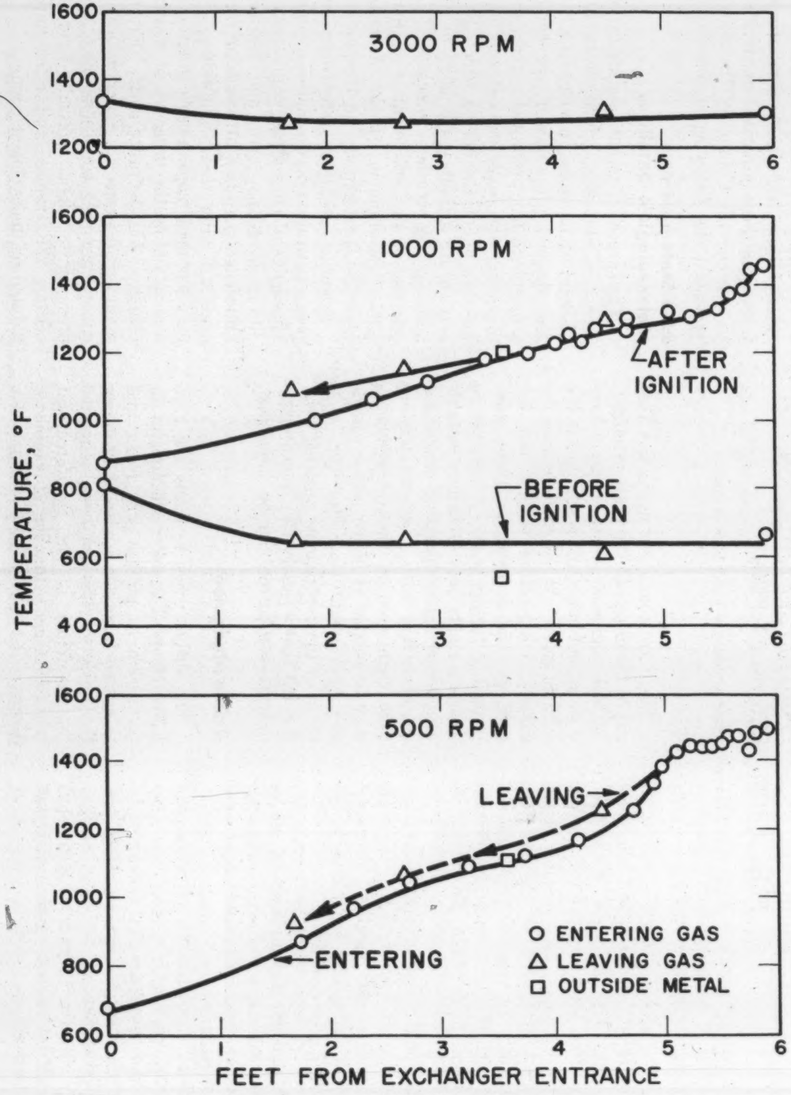

Fig. 10. Heat exchanger temperatures burning auto exhaust with air.

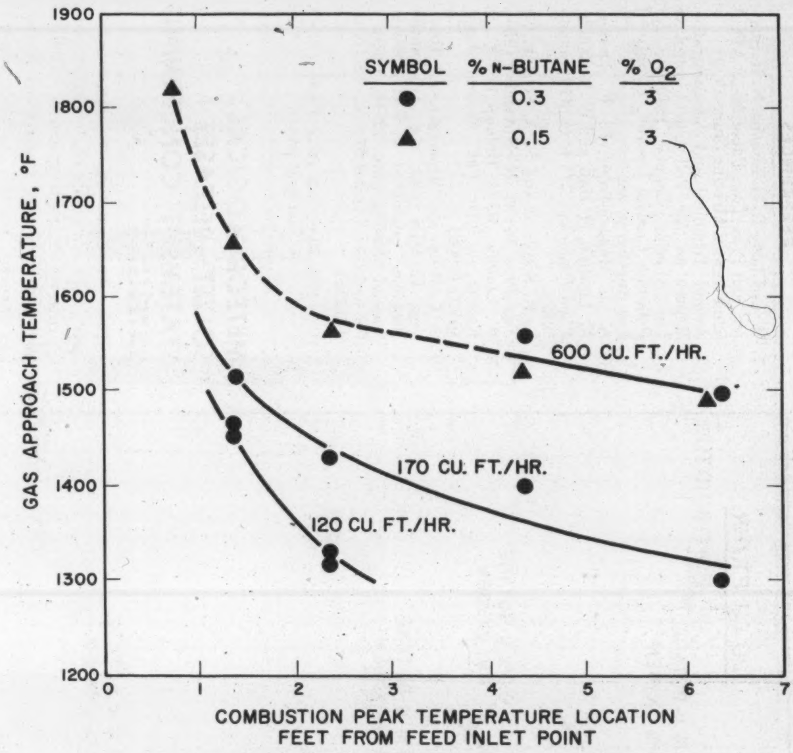

Fig. 9. The effect of flow rate on butane combustion in pilot reactor.

Table III

Engine rpm—no load	500[a]		1000[a]		3000	
Air added, percent on exhaust	None	30	None	13	None	22
Temperatures, °F						
Manifold	725	795	873	1032	1457	1481
End of heat exchanger	360	1580	640	1367	1238	1317
Est contact time, sec	1.6	0.8	1.0	0.6	0.3	0.2
Exit gas analysis, mole % on H_2O and O_2 free basis						
Carbon monoxide	4.3	0.0	3.7	0.0	1.7	0.5
Hydrogen	1.7	0.0	1.4	0.0	0.6	0.1
Total hydrocarbons	0.34	0.07	0.29	0.02	0.17	0.07
Mole percent of Hydrocarbons removed	0	80	9	94	35	73

[a] Burning was started by high engine speed operation.

'Air Pollution Is Everybody's Business' Theme of APCA's 54th Annual Meeting

The 54th Annual Air Pollution Control Association Meeting will be held June 11-15 at the Hotel Commodore in New York City, Harry A. Belyea, Association President and Chief Air Pollution Control Officer of Metropolitan Toronto, Canada, announced. Approximately 500 of the nation's leading authorities of air pollution control are expected to attend the five-day meeting.

Mr. Belyea said the theme of this year's meeting is "Air Pollution Is Everybody's Business."

A. J. Benline, Commissioner, New York City Department of Air Pollution Control, is this year's conference chairman.

Eighteen technical sessions have been planned, at which scientists, researchers, physicians, industrialists, and officials of federal, state, and local governments will present some 80 papers on a wide variety of subjects. Included among the papers will be discussions on instrumentation, pollution standards, health, incineration, fuels, control equipment, meteorology, and research.

On display will be an exhibit featuring the latest instruments and most modern advances in the air pollution abatement equipment field.

One of the highlights of the meeting will be the announcement of the recipient of the Frank A. Chambers Award. The award, named for a pioneer in modern methods of smoke abatement and former head of the Department of Air Pollution Control in Chicago, Ill., is presented annually for a specific act considered to be a major contribution to the science of air pollution control. The Frank A. Chambers Award was not presented in 1960.

R. B. Mellon Award

Another highlight will be the presentation of the Richard Beatty Mellon Award, named for the man, who with his brother Andrew William, established the Mellon Institute of Industrial Research. The award is presented annually to a recipient whose contributions of a civic, administrative, technical, or other nature have aided substantially the cause of air pollution control. Dr. Robert Arthur Kehoe, founder and director of the Kettering Laboratory and head of the University of Cincinnati Institute of Industrial Health, received the award in 1960.

Arrangements for the major keynote session have not been completed. "However," Mr. Belyea said, "it is planned to scrutinize air pollution standards."

Supplementing the business and technical sessions will be the President's luncheon, APCA's gala banquet and review, a preconvention mixer for early arrivals, trips and inspection tours for both ladies and men, and a coffee hour each morning for the ladies.

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ADVISORY COMMITTEE ON COMMUNITY AP IS RECONSTITUTED

The National Advisory Committee on Community Air Pollution has been enlarged and reconstituted, it was announced by the Public Health Service, U. S. Department of Health, Education, and Welfare.

The membership has been increased from 12 to 15, with five members from industry, five from State and local governments, and five representing universities, professional associations, and the public. For the first time, a staggered tenure plan has been established so that five members will be replaced each year with new appointees who will be serving for a term lasting three years.

The committee was first set up in June 1957, by the Surgeon General to advise him on the Public Health Service's policies, objectives, activities, and accomplishments in the air pollution field. Like the newly established PHS Division of Air Pollution, the enlarged National Advisory Committee reflects the concern which is growing about the air pollution problem that is prevalent in our urbanized modern day society.

Present Members of the Advisory Committee

Present members are: P. N. Gammelgard, Vice President, Pure Oil Co., Palatine, Illinois; S. Smith Griswold, Director, Los Angeles Air Pollution Control District; Charles W. Gruber, City Air Pollution Control Officer, Cincinnati; Charles M. Heinen, Assistant Chief Engineer, Materials Laboratories, Chrysler Corporation, Detroit R. Wolcott Hooker, Senior Vice President, Hooker Chemical Company, New York; R. L. Ireland, Chairman of the Board, Pittsburgh Consolidation Coal Company, Cleveland; Edward C. Logelin, Vice President, U. S. Steel Corporation, Chicago; Dr. Louis C. McCabe, President, Resources Research, Inc., Washington, D. C.; Dr. Malcolm H. Merrill, California State Director of Public Health, Berkeley; Mrs. Eugene Meyers, Washington, D. C.; Dr. Norton Nelson, Director, Institute of Industrial Medicine, New York University, New York; Dennis O'Harrow, Executive Director, American Society of Planning Officials, Chicago; Dr. Wilson T. Sowder, Florida State Health Officer, Jacksonville; Raymond R. Tucker, Mayor, St. Louis; and Dr. Oram C. Woolpert, Director, Ohio State University Research Foundation, Columbus, Ohio.

SECTION HI-LITES

West Coast Section

The future of air pollution control in Southern California was the subject of the Winter Dinner meeting of the West Coast section held February 1 at the Petroleum Club. Air Pollution Control officers of five Southern California counties, John Fairweather, San Bernardino County; William Fitchen, Orange County; Kenneth N. Flocke, San Diego County; S. Smith Griswold, Los Angeles County; and Clifton J. Seymour, Riverside County examined such questions as: What new air pollution control measures can we expect in the next year? Will automotive control ease the burden on industry? Will control programs increase in intensity? The newly elected officers of the West Coast Section were also introduced. They are: Chairman, John H. Fairweather; Vice-Chairman, John H. Easthagen; Secretary-Treasurer, Robert G. Lunche; Executive Committee (Elective), H. Carter Austin, George J. Taylor, and Clifton J. Seymour; and Executive Committee (Ex officio), Gerald Fisher, W. L. Faith, and R. E. Hatchard.

The co-chairmen for the program were James Daily and Raymond G. Holmes.

Niagara Frontier Section

Roy Warren of the Buffalo Forge Company moderated the annual "Manufacturers' Panel on Control Equipment" at the meeting of the Niagara Frontier Section, January 26. Members of the panel included representatives from Airkem, Inc., who discussed odor control; Ducon, west scrubbers; Joy Manufacturing, electrostatic precipitators; and the Koppers Company, fabric collectors. In addition, Mr. Warren examined types of mechanical collectors and other control techniques.

REPRINTS
of
Journal Articles
and
Annual Meeting
Papers
Available Through
APCA HEADQUARTERS

AIR POLLUTION BILLS WERE INTRODUCED AT 87TH CONGRESS

Although the 87th Congress had scarcely time to organize, six bills concerning air pollution were introduced in rapid-fire succession.

In introducing HR3083, Congressman Roberts of Alabama once again took the lead as he did last year in calling for amendment of Public Law 159. The draft bill includes amendments which would:

a Eliminate the time limitation and $5 million ceiling on annual appropriation included in the current act.

b Authorize the Surgeon General to make investigations and to hold public hearings on air pollution problems which are interstate in nature or are of broad significance.

c Delete the requirements for allotment of funds appropriated for grants-in-aid and contracts in accordance with regulations prescribed by the Secretary of Health, Education, and Welfare.

Bill S455 introduced in the Senate by Senator Kuchel of California is a companion bill to HR3083; this is a repetition of 1960 when these two identical bills were introduced, but were not enacted.

HR2948 Introduced by Shelley

HR2948 was introduced by Congressman Shelley and is almost identical with that of Congressman Roberts.

HR747 introduced by Congressman McDonough calls for federal agencies to co-operate with federal, interstate, state, or local government air pollution control agencies in preventing or controlling air pollution.

HR1189 by Congressman McDonough provides that the secretary of Commerce shall furnish weather reports to certain air pollution control agencies upon request.

Perhaps the most significant piece of legislation introduced was Bill HR924 by Congressman Byrnes of Wisconsin. This is a bill "to encourage the prevention of air and water pollution by allowing the cost of treatment works for the abatement of air and stream pollution to be amortized at an accelerated rate for income tax purposes." Similar to other legislation of this type proposed as early as five years ago, the main feature of this bill calls for accelerated amortization deductions based on a period of 60 months, subject to certain qualifications.

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C. I. C. A. D.
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Santa Monica, California

Purolator Products, Inc.
Rahway, New Jersey

Toronto Refiners & Smelters Company
Toronto, 2B, Ontario, Canada

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Pullman, Washington

Anton, George T.
Rockville, Maryland

Aubertel, Theodore M.
New York, New York

Bailey, W. R.
The Dalles, Oregon

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Broderick, Harris G.
San Bernardino, California

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Los Angeles, California

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Hicksville, L. I., New York

Calkins, Charles H.
Portland, Oregon

Callahan, Edward L.
San Marino, California

Carpenter, S. B.
Wilson Dam, Alabama

Clark, F. J.
Buffalo, New York

Cramer, Robert S.
Richmond, California

Davis, Edward W.
Albany, New York

Dawson, Jack
Niagara Falls, New York

Delaney, George A.
Detroit, Michigan

Devitt, Gerald E.
Livonia, Michigan

DelGuercio, Victor
Trenton, New Jersey

Duckworth, Fowler S.
Menlo Park, California

Dreisinger, B. R.
Sudbury, Ontario, Canada

Drossel, Gene
Oakland, California

Eady, Keith R.
Niagara Falls, Ontario, Canada

Faith, W. L.
San Marino, California

(Continued on p. 143)

Welcome New Members

(*Continued from page 142*)

Fischoff, Robert L.
Cincinnati, Ohio
Gary, Wright W.
Beverly Hills, California
Golden, Jack
Bronx, New York
Hambright, James K.
Philadelphia, Pennsylvania
Hawthorne, Charles W.
Etiwanda, California
Heberlein, Max F. W.
Rahway, New Jersey
Hellmers, H. D.
Westend, California
Huffstutler, K. K.
Winter Haven, Florida
Hughes, E. C.
Cleveland, Ohio
Iinoya, Koichi
Atlanta, Georgia
Ilgenfritz, Edgar M.
Midland, Michigan
Imhoff, Camden L.
Erie, Pennsylvania
Lazenka, Clemens A.
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Manley, Pierce J.
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Marlow, Sidney
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Matlin, A. J.
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McHenry, Charles R.
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Marcus Hook, Pennsylvania
Meissner, H. G.
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Washington, D. C.
Robson, Frank Lambert
Artarmon, N. S. W., Australia
Roy, Louis Philippe
Montreal, Quebec, Canada
Rovegno, Albert
Staten Island, New York

(*Continued on page 144*)

Election Results Announced by AMS

The election of officers and members of the Council of the American Meteorological Society was announced at the 41st Annual Business Meeting of the Society at the Barbizon-Plaza Hotel, New York City. The President, Dr. Thomas F. Malone, Director of Research, The Travelers Insurance Company, Hartford, Connecticut, and the Vice President, Patrick D. McTaggart-Cowan, Director of the Canadian Meteorological Service, Toronto, Ontario, were elected for a two-year term of office at the Society's 40th Anniversary Meeting in January 1960.

Two officers were re-elected for the coming year: Dr. James M. Austin, Associate Professor of Meteorology, M.I.T., as Secretary of the Society, and Henry DeC. Ward, Vice-President of Eaton and Howard, Inc., of Boston, as Treasurer of the Society.

Five new Councilors, elected for a three-year term, are: Henry T. Harrison, Director of Meteorology, United Air Lines, Denver, Colorado; Dr. Daniel F. Rex, Capt., USN, Staff, CINCLANT/SACLANT, Norfolk, Virginia; Dr. Gerald L. Barger, Deputy Director, National Weather Records Center, Asheville, North Carolina; Dr. William W. Kellogg, Chief, Planetary Sciences Group, The Rand Corporation, Santa Monica, California; and Dr. Woodrow C. Jacobs, Science and Technology Division, The Library of Congress, Washington, D. C.

In Memoriam . . .

It is with deep regret that we announce the death of Luke Ellis, longtime member of APCA and former Smoke Abatement Engineer of Baltimore, on December 11, 1960.

Professor W. W. Hodge, Senior Fellow, Koppers Company at Mellon Institute, died January 23, 1961.

AP Foundation Board Approves Liquidation; Authorizes Research

At the annual meeting of the Air Pollution Foundation Board of Trustees held November 3, 1960, several grants for further research were authorized and plans for liquidation of the Foundation were approved.

Stanford Research Institute was granted $50,000 cash, together with an estimated $40,000 worth of equipment now being used in SRI's South Pasadena laboratories, for continued research in atmospheric chemistry.

A cash grant of $10,000 was made to University of Southern California for studies on air pollution, and equipment valued at $5000 was turned over to Southwest Research Institute, San Antonio, Texas, for continued studies on automobile exhaust.

Upon final dissolution of the Foundation on or about next May 31, all remaining assets will be donated to California Institute of Technology for additional research work in the field of air pollution. It is impossible to estimate the probable value of the residue assets at this time.

CLASSIFIED

A medium size firm located in Western Germany with 40 years' experience in developing and constructing large fans and mechanical dust extractors using centrifugal force is interested in **taking over licenses** of standard firms in the field of fabric filters, wet filters, pneumatic high pressure conveying plants and high pressure blowers for the purpose of enlarging production. We can offer a well organized drafting department, outstanding production service and sales department. We have good relations with the cement, mining, chemical and mineral oil industries as well as with shipyards. Box F

CALENDAR

March 21–23	23rd Annual Meeting of American Power Conference, Chicago, Illinois
March 27–31	Symposium on Temperature, Its Measurement and Control in Science and Industry, Instrument Society of America, Columbus, Ohio
April 9–13	American Industrial Hygiene Conference, Detroit, Michigan
April 18–20	International Symposium on Chemical Reactions in the Lower and Upper Atmosphere, San Francisco, California
June 11–15	**54th Annual Meeting of APCA, Hotel Commodore, New York, New York**

NEWS FROM THE CONTROL DISTRICTS

New York City

New Yorkers were asked to help the Department of Air Pollution Control by furnishing information as to specific sources of air pollution from heating equipment during the winter months. At the same time, Commissioner Arthur J. Benline called upon building owners and building superintendents to reduce air pollution or face the prospect of punitive enforcement action by the Department.

In his appeal to the citizens, Commissioner Benline stressed the need for accurate information as to specific sources of air pollution, particularly from heating equipment. "It is of little help to us to be told that a whole area has air pollution," he said, "but it is of great help to our staff of 36 inspectors if citizens complaints actually pinpoint the location and time of the alleged violation."

Commissioner Benline told operators of heating equipment that proper maintenance and operation can reduce air pollution and save on fuel costs. He warned that violations of the Department's Rules and Regulations will result in the issuance of summonses, which carry a minimum fine, upon conviction, of $25 for the first offense.

City of Columbus

We received reports of another balloon being found in Virginia, this makes two that have been found. Approximate distance by air is 310 miles.

The division was happy to read December 9 issue of the *Dispatch,* where producer-director Pasternack of Hollywood commented on the clean air in Columbus.

The article by Phyllis Nash was spread over two full pages of the *A.S.M.E. Smog News.* This is a one line description of the divisions operations, "The Air You Breathe." The division has received many comments on this article from other air pollution control agencies.

The Advisory Board held a meeting on December 1, and discussed matters pertaining to improved operation of the division.

All attempts to have ordinances passed for trash and debris burning without the city failed during the month. This is commonly called or referred to as "on site burning."

The snow cover for about 40% of the month accounts for the lower dust fall registered.

Bay Area

The Board of Directors of the Bay Area Air Pollution Control District voted to ask the State Legislature to amend the District's law to provide a one-cent increase in the District's permissible tax rate.

The vote was eight in favor, two against, one abstaining, with one absent.

The additional funds may be needed for effective enforcement of the District's anti-smog regulations by the District staff and to reimburse local agencies for enforcement work carried on by them under the Board's co-operative enforcement policy.

Director McMahon introduced a resolution, adopted unanimously by the Board, requesting the Board memorialize the Congress of the United States to enact legislation providing the quickest possible tax write-off for capital expenditures for air pollution control equipment. Director Francis Dunn suggested that a letter and a copy of this resolution be sent to the State Legislature requesting that they take similar action.

A resolution, introduced by Director William C. Blake, requesting the Board's Legislative Committee to seek an amendment to the District law establishing misdemeanor power for the District was referred to the Legislative Committee for study and recommendation to the Board at the February meeting.

Philadelphia

Permit approval was given for the following control installations: two paint spray booths with a total capacity of 11,000 cfm; seven incinerators with a total capacity of 1570 pph; a pathological incinerator with a capacity of 75 pph.

An industrial building under new ownership has replaced their old power plant equipment with a modern unit provided with adequate combustion controls. In the past, a frequent smoke condition resulted from hand firing of coal made necessary when their stokers broke down; a wet centrifugal collector to wash the gases evolved from an acid plating tank and laboratory hood at an electrical equipment manufacturer. This installation should effectively eliminate the source of acid odor complaints from another office located in this same building.

Six major office conferences were held regarding the following: Smoke from boiler stacks; Soot from boiler stacks; Smoke and fly ash from incinerators; Dusty processes; Odorous processes.

(*Continued on p. 145*)

ENGINE BLOWBY

(*Continued from p. 117*)

REFERENCES

1. P. A. Bennett, M. W. Jackson, C. K. Murphy, R. A. Randall, "Reduction of Air Pollution by Control of Emission from Automotive Crankcases," presented at the SAE Annual Meeting, Detroit, Mich. (Jan. 11–15, 1960).
2. J. Q. Payne and H. W. Sigworth, "The Composition and Nature of Blowby and Exhaust Gases from Passenger Car Engines," *Proc. of 2nd National Air Pollution Symposium* (1952).

Welcome New Members

(*Continued from p. 143*)

Samuels, Sheldon W.
Albany, New York

Schafer, Lawrence J.
Cincinnati, Ohio

Serata, Shosei
East Lansing, Michigan

Sharp, R. D.
Marcus Hook, Pennsylvania

Shustack, Stanley B.
Encino, California

Simon, Jack B.
Los Angeles, California

Sloane, Eugene A.
Detroit, Michigan

Strachan, Ronald
Orange, California

Swartz, Dorian J.
Los Angeles, California

Thompson, Norman P.
Los Angeles, California

Townsend, Henry D.
Windy Hills, Newark, Delaware

Walton, Alan
Westwood, New Jersey

Webb, Walter W.
St. Catharines, Ontario, Canada

Wolfmuller, William C.
New York, New York

Woods, Edward A.
Cambridge, Massachusetts

Yao, Cheng
Union, New Jersey

Yeager, J. S.
Riverside, California

Zimney, C. M.
Pasadena, California

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Petri dishes & collection plates
Write for further information
ANDERSEN SAMPLERS & CONSULTING SERVICE
1074 Ash Avenue, Provo, Utah

CONTROL DISTRICTS

(*Continued from p. 144*)

Four administrative hearings were held with: a refractory manufacturer re open burning of refuse; an apartment building re incinerator flash; an auto wrecker re open burning trolley cars; a refuse hauler re open burning of refuse.

There were 10 vehicle violations reported this month. These included two buses, one truck, and seven automobiles. Compliance was obtained on two automobiles. To date a total of 10 compliances for 44 violations have been obtained.

Allegheny County

Industry

J. R. Garvey, Vice President and Director of Research, Bituminous Coal Research, Inc., and J. E. Norton, Administrative Assistant, Consolidation Coal Company, met with the Chief to discuss procedures and practices that will be used to keep the Bureau informed in advance when dense smoke will be emitted from the new Bituminous Coal Research Laboratories now under construction in Monroeville. Such emissions are a necessary part of their research program in developing equipment and techniques for controlling smoke emissions, and may be permitted under the provisions of Section 1310.4 of the Rules and Regulations.

Discussions have been held separately with Duquesne Light Company, West Penn Power Company, and Jones and Laughlin Steel Corporation representatives regarding modification in their respective proposals for controlling the particulate emissions from certain of their fuel-burning equipment.

Incinerators

A severe odor nuisance occurred from December 2 through December 6 from the incinerator at the Allegheny County Sanitary Authority 'Sewage Treatment Plant. Various combinations of their four furnaces were placed into service until the odor vanished. They are now installing separate ports into the breeching of each furnace for sampling so that in the future they can determine immediately which furnace is causing the trouble. The trouble in this case was caused from a ruptured tube in the deodorizing chamber.

Gob Pile Fires

Six gob pile sites were inspected where fires have been experienced recently. Two were still burning, namely the Mongah Gob Fire in Forward Township and the Borota Dump in Jef-

(*Continued on page 146*)

• • • Personalia • • •

Jerome Wilkenfeld has been promoted to technical superintendent of the Niagara Falls plant of the Eastern Chemical Division, Hooker Chemical Corporation, succeeding Walton B. Scott who held this position since 1950. Until his retirement on February 1, Mr. Scott will be special assistant to Maynard L. Parker, works manager, who made the announcement.

Mr. Wilkenfeld is the industrial member of the New York State Air Pollution Control Board, and in this field has been a lecturer and panelist at various air pollution control conferences in New York State and elsewhere. He is also vice chairman of the water pollution abatement committee of the Manufacturing Chemists' Association.

* * *

J. H. Dennis

J. H. Dennis, manager of manufacturing, has assumed full responsibility for all manufacturing divisions and operation of Bailey Meter Company's three Cleveland plants, according to an announcement by President P. S. Dickey. In this capacity Dennis succeeds Vice President C. E. Sutherland who retired on Dec. 31, 1960.

During his 23 years with the company, Dennis has worked in contract engineering, proposition, education, and industrial relations. Last year he was named manager of manufacturing.

* * *

Robert D. Wright formerly with Alta Corporation Ltd. of Johannesburg, South Africa, is now Chief Technical Executive of the Midland Heating and Ventilation Company, Ltd., Birmingham, England. He is also living in England.

* * *

John E. Yocom, director of technical services of the Bay Area Air Pollution Control District has accepted a position as senior staff member with the Western Division Laboratories of Arthur D. Little, Inc.

Mr. Yocom who will join the staff next month will work with Dr. Herbert Bandes, research and development director of Arthur D. Little, West Division, on process modification research and air pollution controls for industry.

Prior to joining the Bay Area Air Pollution Control District staff in March 1957, Mr. Yocom was with Battelle Memorial Institute, Columbus Ohio, for 10 years where he was a project leader for air pollution studies and the design of air pollution instruments.

* * *

Philip S. Tow has been named by the Sacramento County Air Pollution Control District Air Sanitation Engineer. He is the first full-time employee of the District.

Mr. Tow is in charge of the technical activities of the District, evaluating the county's air pollution problem, recommending what measures, if any, are needed to remove the problem, and acting as a consultant to the public. Prior to his appointment, he had been with the Los Angeles County Air Pollution Control District for ten years, most recently as a Head Research Assistant.

* * *

John L. Maloney, formerly an Air Pollution Engineer with the Los Angeles County Air Pollution Control District, has been employed in a similar capacity with the Riverside County Air Pollution Control District. Clifton J. Seymour has been the District's only engineer for three years.

* * *

Spencer Duckworth, formerly with Stanford Research Institute, has succeeded Elmer Robinson as Chief, Air Analysis, for the San Francisco Bay Area Air Pollution Control District. Joseph D. Coons, formerly Principal Engineer with the District, was named as the District's Director of Enforcement to handle the increased enforcement activity necessitated by the passage of the District's Regulation No. 2.

* * *

Donald A. Jensen, formerly Marin County chief administrator, is the newly appointed Executive Officer of the California Motor Vehicle Pollution Control Board. His responsibility will be to assist the Board in developing a program for the control of auto exhaust, a major contributor to smog.

In making the announcement, Dr. John T. Middleton, Chairman of the Motor Vehicle Pollution Control Board, said that the Board considers Mr. Jensen "ideally suited to the difficult organizing work that must be done before auto exhaust can be eliminated as a contributor to smog.

Mr. Jensen will be responsible for putting into action the 1960 State Legislature's mandate to the Motor Vehicle Pollution Control Board to seek

(*Continued on p. 146*)

EXHAUST FUME CONTROL NOT ENOUGH TO CUT SMOG

Control of unburned automobile exhaust fumes won't be enough to cut down the smog problem. Designers will have to plug other leaks which permit hydrocarbons to escape into the atmosphere.

This view was given by Southwest Research Institute engineer Kenneth D. Mills in a report prepared for the Motor Vehicle Pollution Control Board of California.

Unburned hydrocarbons which are chemically changed by the sun's rays have long been known to be one of the major causes of the eye watering, plant damaging smog which has plagued many of our major cities.

Studies have been made of possible chemical devices, catalytic afterburners—or direct flame afterburners which would oxidize the exhaust gases.

However, Mr. Mills says, even the most efficient exhaust control device would only make the auto a little more than half safe. The automobile industry has recognized the importance of crankcase "leaks" and has already voluntarily taken design steps to reduce this smog source.

Noting that the crankcase emits both the unburned gas which escapes between the piston and the rings (blowby) and the oil vapors, it has been suggested that these fumes be recirculated through the combustion system and again attempt to burn them.

Mr. Mills states that this system will reduce the percentage of hydrocarbons which are vented into the atmosphere, but he points out that it may also result in gummy deposits on valves and pistons.

Instead he suggests that the crankcase fumes be channeled to the afterburners and oxidized there with the exhaust gases.

Mr. Mills calls for further research on such a system and also studies of gas which escapes from the carburetor.

PERSONALIA

(*Continued from p. 145*)

and eliminate the major contribution of auto exhaust to the growing California smog problem.

"Jensen will act as a liaison man between the Board and the auto industry plus the many chemical and engineering groups working on exhaust control devices. He will also develop co-operative arrangements with air pollution control districts, technical and research groups, and testing laboratories for the eventual certification of devices that will control auto exhaust pollutants" according to a Board announcement.

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. PUBLIC RELATIONS

Boston—Washington—New York

CONTROL DISTRICTS

(*Continued from p. 145*)

ferson Borough. Continued field visits will be made until these fires are extinguished.

City of St. Louis

Mayor Raymond R. Tucker today signed an ordinance recently passed by the Board of Aldermen marking another step forward in St. Louis' battle against polluted skies. The measure abolishes the present division of smoke regulation, which dates back to 1937, and establishes in its stead a division of air pollution control combining the duties of both the smoke and the health divisions.

St. Louis' anti-smoke ordinance, the first of its kind and the first to meet with marked success in any major city, was aimed at the elimination of smoke and other nuisances "caused by and directly resulting from the combustion of fuel or refuse." The control of all other types of industrial air pollution not caused by burning has been the responsibility of the health division. Here it has been handled by the industrial hygiene section, although in recent years there has been no full time employee on this work.

LAUREN B. HITCHCOCK ASSOCIATES
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CORPORATION FORMED; ANNOUNCED BY BOARD

Formation of a new Canadian company, Wheelabrator Corporation of Canada, Ltd., is announced by James F. Connaughton, chairman of the board.

The new corporation is the successor to the Canadian Division of Wheelabrator Corporation of Mishawaka, Indiana, and was organized in order to handle expanding sales and fabricating activities for all provinces located in Canada.

Wheelabrator supplies airless blast cleaning equipment, abrasives, and dust and fume collection systems from its plant in Scarborough, Ontario. It also has an office located in Montreal, Quebec.

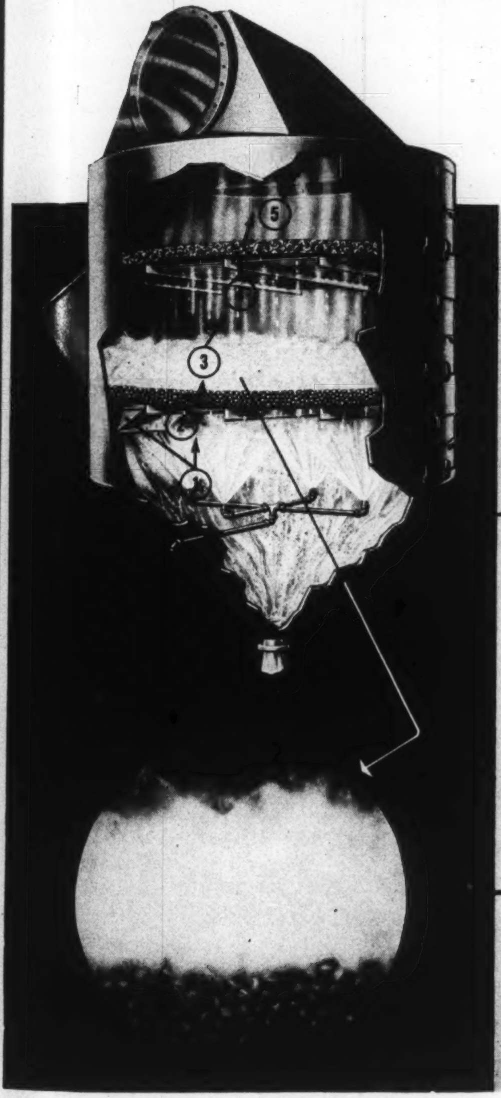
Harold M. Miller is president and Robert A. Campbell is vice president and general manager and is in charge of Canadian operations. J. D. Lamb has been named to the position of general sales manager.

Other officers are Jacob A. Schmidt, Jr., vice president; Edward T. Sullivan, secretary and treasurer; and James E. Donlan, controller.

Wheelabrator is a subsidiary of Bell Intercontinental Corporation.

Here's a Dust Collector that Cleans Itself!

- A WET SCRUBBER FOR DUST and FUME CONTROL
- NOT AFFECTED BY FLUCTUATIONS IN VOLUME AND VELOCITY OF FLOW
- HIGH, CONTINUOUS EFFICIENCY
- SIMPLE DESIGN AND OPERATION INSURES:
  Low operational costs and minimum maintenance
  Low static loss
- SELF-CLEANING ACTION IS CONTINUOUS



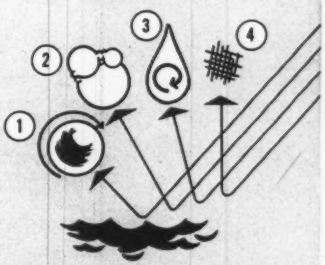
HERE'S HOW IT WORKS

1. Large dust particles are thrown out upon entering collector.
2. The air with its remaining dust load starts a tortuous, deflective path through the bed packed with glass spheres. Dust is impinged at high velocity on wetted surfaces and flushed downward continuously.
3. Air is converted to bubbles in pool of violently turbulent water and mist maintained above filter bed. Small dust particles are trapped in water droplets and are flushed downward. Maximum air-water contact time is obtained in (2) and (3).
4. Air approaches moisture eliminator bed through more mist and droplets. Moisture is removed by impingement on packing media and returned to the bottom of the collector.
5. Clean air is exhausted to atmosphere.

STOPS DUST 4 WAYS

Four-way particle separation is effected as shown in the diagram at right.

1. *Impingement on wetted surface of glass spheres.*
2. *Impingement on bubble surfaces and . . .*
3. *Entrapment within falling water droplets.*
4. *Impingement on wetted surface of collection area.*



NO BAFFLES
. . . to wear, corrode, or "load up" within collection area.

NO INTRICATE PARTS
. . . to clean. Water action and glass spheres do the work with Hydro-Filter.

NO DEAD AREAS
Entire interior is constantly flushed. Every inch is used to collect dust particles.

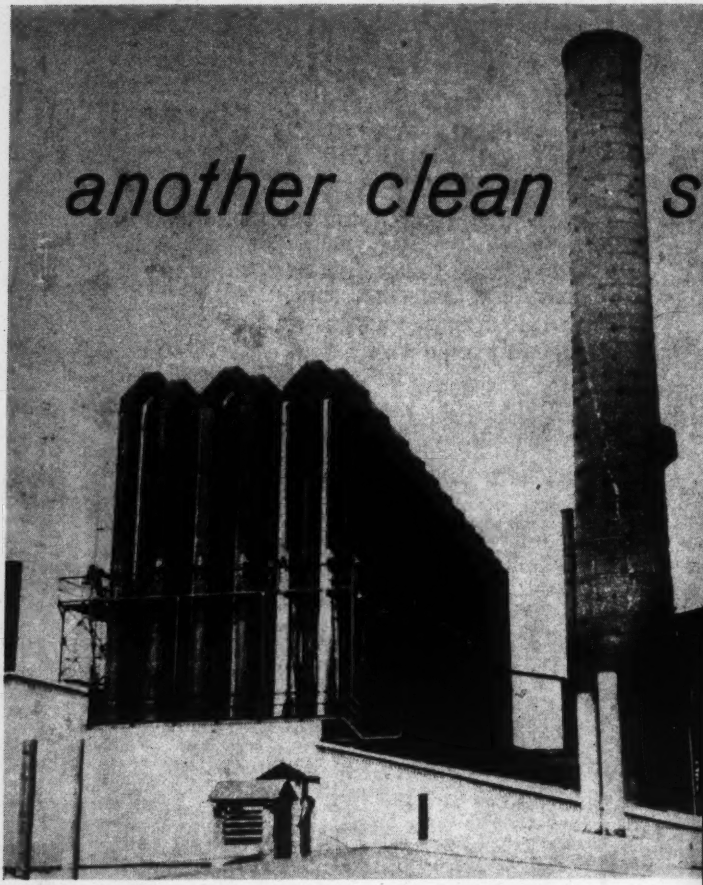
▲

TURBULENT LAYER

This violent turbulent layer of water—bubbles and mist—is the "heart" of the Hydro-Filter principle of dust and fume separation. It provides maximum gas-water contact and its efficiency as a separation medium is unaffected by large variation in volume and velocity of gas flow. The layer provides hydro-static head to continuously backwash the filter bed.

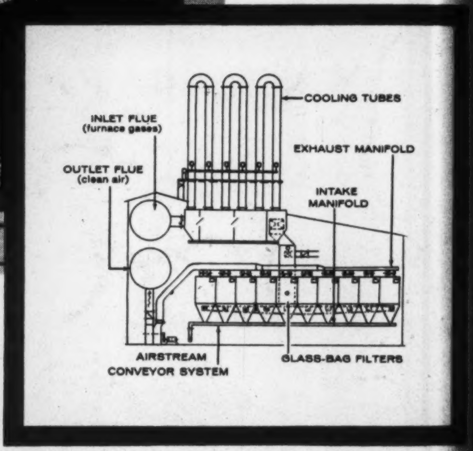
For details write:

National Dust Collector Corp.
601 Machinery Hall Building,
Chicago 6, Illinois



(Left) Cooling tubes atop Glass-Bag Filter housing lower furnace gas tempera-ture from 800°F. to 450°, a full 150° below maximum advisable operating tempera-ture. Clean stack proves that filter removes all visible dust.

(Below) System consists of 12 ten-compartment Glass-Bag Filters. Gases at 800° are blown from electrostatic precipitator to cooling tubes which discharge to filter sys-tem, resulting in daily col-lection of about 35 tons of material.



. . . "trade mark" of the Dracco Glass-Bag Filter

Freedom from hot, corrosive dust created by metallurgical processes is one of the many benefits of using Glass-Bag Filters. The clean stack shown in the unretouched photograph testifies to the effectiveness of the Dracco system at Hudson Bay Mining & Smelting Co., Ltd., Flin Flon, Manitoba.

Here is what the system does for Hudson Bay:

- **handles 450,000 cfm of mixed reverberatory furnace and converter gases at 450°F.**
- **recovers approximately 35 tons of valuable metal oxide dusts daily.**
- **maintains operating temperature to prevent condensation of exhaust gases and formation of corrosive acid dews.**
- **eliminates air pollution**
- **reduces cooling equipment requirements, and costs, by 50% over conventional methods.**
- **provides low-maintenance operation and gentle bag cleaning with SWING-CLEAN.**

Glass-Bag Filters, the most advanced equipment now available for fighting air polution and hot dust, have been proved-in-performance in the metallurgical, chemical and cement industries. Virtually 100% collection efficiency is maintained at temperatures to 600°F. Maximum bag life is assured by either of two patented cleaning devices: (1) a mechanism for dust removal by sonics and (2) SWING-CLEAN, gentle swaying action.

For full details on how Glass-Bag Filters can help you lick that hot dust problem, write: Dracco Division of Fuller Company, Harvard Avenue and East 116th Street, Cleveland 5, Ohio.

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dust control equipment